SEDIMENT DYNAMICS IN IRRAWADDY RIVER, MYANMAR

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SUMMARY

Sediment dynamics in a river basin consist of high rate of soil erosion, sediment transportation and deposition processes. The impacts of changes on climate and human intervene including land use activities and water discharge will affect the soil erosion and sedimentation to the river. The relationship of land use change effect on water discharge and sediment flux at the basin is crucial study for the Lower Irrawaddy basin in Myanmar.

The availability of global environmental datasets and selected modeling approaches with Geographical Information System (GIS) and Remote Sensing (RS) techniques are helpful information and the assessment of spatial scale study particularly un-gauged large basins. The current research demonstrated for Thornes Soil erosion Model and complex spatial information to improve estimation of soil erosion rate and sediment delivery source to sink.

Following this approach, the framework stage is presented for constructing sediment dynamics for large Irrawaddy basin. The research consists of five stages of data retrieving, Land use and land cover change time series analysis, Thornes model construction, experiments field study of sediment discharge measurement and geo-sediment sampling, suspended sediment analysis in laboratory and implementation and the sources of sediment in lower Irrawaddy basin. The study area had sub-tropical climate and annual rainfall was 1563 mm and annual runoff was 1012 mm/year at Pyay station in 2002. The study focuses on the validity of GIS based runoff methods of SCS-CN methods and applied to estimate the runoff rates.

In compilations of global river statistics, the Irrawaddy is currently ranked fifth largest for suspended sediment load (265MT/year). Previous studies which have analyzed the water and sediment flux are derived from an original 19^{th} Century dataset by Gordon (1885) (261MT/year) and a more recent study of discharge and suspended sediment load by Furuichi et al. (2009) ($325 \pm 57x10^{6}$ t/year).A field programme on modern discharge and sediment load measurements suggests that the original 19th century data underestimated the actual sediment load Robinson et al. (2007) suggest the sediment load is ($364 \pm 60 \times 10^{6}$ t/year).

The current research demonstrated a field study measurement of Sediment concentration (SSC) with Acoustic Doppler Current Profiler (ADCP) for water discharge measurements and water sampling and total Suspended Sediment (TSS) concentration .As a result of human disturbance of the landscape processes, runoff and associated river discharge, which results are effect on sediment flux in the Irrawaddy River. In addition, this research would be able to explain suspended sediment dynamics in large river systems in deposition of sediment budgets and impact of land use change on sediment movement of basin scale.

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LIST OF ABBREVIATIONS

ADCP	Acoustic Doppler Current Profiler
DEM	Digital Elevation Model
ENSO	El Niño/La Niña-Southern Oscillation
ETM+	Enhanced Thematic Mapper
FAO	Food and Agriculture Organization
UNESCO	United Nations Educational, Scientific, and Cultural Organization
GIS	Geographic Information System
LUCC	land use and land cover changes
MSS	Multispectral Scanner
NDVI	Normalized Difference Vegetation Index
RS	Remote Sensing
SCS-CN	Soil Conservation Service Curve Number
SE Asia	South East Asia
SOI	Southern Oscillation Index
SSC	suspended sediment concentration
SST	Sea Surface Temperature
TM	Thematic Mapper
UNFCCC	United Nations Framework Convention on Climate Change
USGS	United States Geological Survey

1. INTRODUCTION

1.1 Background of the study

The Irrawaddy River (local name: Ayeyarwady; length 2170 km; drainage area 413,710 km^2) is one of the great rivers in Asia. There have been few studies of river sediment and soil erosion within the large drainage basin of the Irrawaddy. The headwaters originate in the eastern syntaxis of the Himalayas and Tibetan Plateau and it discharges into the Andaman Sea. Some previous studies have focused on the water discharge, sediment and dissolved load of the Himalayas and Tibetan Plateau to the ocean and estimate that ~ 20% of this sediment load can be attributed to the Irrawaddy and Salween River (Milliman and Meade 1983). In compilations of global river statistics, the Irrawaddy is currently ranked as fifth largest for suspended sediment load (265MT/year). As such it plays a significant role in the global transfer of sediment from terrestrial to ocean environments. However, there are limited data on the sediment budget of large river basins in this region. Previous studies which have analyzed the water and sediment flux are derived from an original 19th Century dataset by Gordon (1885) (261MT/year), a more recent study of discharge and suspended sediment load by Furuichi et al. (2009) (325 ± 57 MT/year), and a field programme on modern discharge and sediment load measurements which suggests that the original 19th century data underestimated the actual sediment load. Robinson et al. (2007) replicated the sampling design of Gordon's original monitoring programme and suggest the recalculated sediment load is 364 ± 60 MT/year. Estimating the suspended sediment flux and sediments discharged to the ocean has proved to be very difficult. Given the very significant contribution of the Irrawaddy

River to global sediment budgets, there remains much to understand about the connection between river basin development activities of Asian Rivers and the transport of sediment and associated nutrients to Global Oceans.

Sediment is a natural component of the fluvial system and it contributes to physical, chemical and biological disruption of river discharge and water quality. In order to manage river basins effectively and to understand their sensitivity to environmental change, it is necessary to have some more information on basin sediment dynamics. A number of natural and anthropogenic factors influence the water and suspended sediment flux of a river basin along its pathway. Land use changes have an impact upon the seasonal sediment load relative to the water flow and most of these changes are caused by human activities such as deforestation, agriculture and construction of reservoirs. The changes of water flow and sediment flux in both wet and dry seasons for some tributaries have significant implications with respect to flooding and water shortages. The processes of erosion and prediction of sediment delivery are complex at the large basin scale. Quantifying sediment delivery in large river basin may involve the use of a combination of empirical and statistical analysis, conceptual and physically based models. This thesis includes a review of the relevant literature and modeling techniques and description of the field study component of the research. The investigation of datasets with Geographical Information Systems (GIS) and Remote Sensing (RS) techniques are useful for studying changes in the large Irrawaddy basin. One of the important factors increasing sediment yield is caused by land use change and may affect both water and sediment discharge at the basin scale. Evaluating the potential impact of land use change is crucial for both academic study and decision making related to economic and technical development. Investigation of the sediment dynamics in the Irrawaddy basin is needed to gain a better understanding of the river system for further research. Therefore, this study seeks to contribute towards a better understanding of sediment fluxes, sources and sinks within the Irrawaddy River basin and how these sediment delivery processes are affected by climate and land use changes in a large river system. High rates of erosion and sediment delivery contribute to sedimentation throughout the Irrawaddy River basin to the delta. However, relatively little is known about sediment delivery dynamics, but it is extremely important for river ecology, sediment dynamics and nutrient transport. The sediment budget has broad effects upon several processes in the Irrawaddy River basin which are of serious concern. The sediment load may be increased by natural and human impacts. Land use change, primarily for agricultural expansion and rapid urbanization in the past several decades have been widespread in the Irrawaddy basin. The population of Myanmar has increased from 4-5 million (1870s) to ~59.12 million in 2009s (Ministry of Immigration and Population, Myanmar, 2010). Myanmar total forest cover has gradually decreased to 392180 km^2 in 1990, to 348680 km^2 in 2000, to 333210 km^2 in 2005 and to 317730 km^2 in 2010 (FAO Report 2010). Such changes lead to environmental degradation through soil erosion and sediment and nutrient loss into the river system. The study therefore aims to contribute towards improved understanding of suspended sediment dynamics in large river Irrawaddy river system and the impact of land use change on sediment mobility.

1.2 Aims and Context of Study

The thesis project has arisen from participation in a joint British-Myanmar research collaboration investigating sediment load and provenance in Myanmar's two largest rivers, the Irrawaddy and Salween. The research collaboration has been based on a Memorandum of Understanding between St Andrews University, UK and Yangon University of Distance Education (YUDE), Myanmar. Scientists from the National University of Singapore (NUS) were also involved in the collaborative project.

The international project is concerned with elucidating the nature of the suspended sediment load in both rivers as means of examining their relative contribution to the terrestrial-ocean transfer of sediment and associated nutrients. In the Irrawaddy basin, the international project concentrated its efforts in the lower Irrawaddy by establishing a gauging station at Pyay and conducting several cross-section surveys at different times of the year to collect water samples from selected depths in the water column and to measure flow properties using an Acoustic Doppler Current Profiler (ADCP). The group also conducted a re-analysis of the nineteenth century discharge and sediment concentration measurements conducted under the organization of James Gordon, an engineer of the Irrawaddy Flotilla Company. Daily discharge was recorded for ten years from 1869 to 1879 and for one year (1878-1879) suspended sediment was measured at daily intervals from nine positions across the channel (Gordon 1879, 1885). The monitoring was conducted in relation to the design of flood levees at Seitkha, which is about 50 km downstream of Pyay. The project team also conducted cross sections at this site. Preliminary work from the project team has resulted in publications about the recalculated sediment load of the Irrawaddy and the implications for assessing the relative contribution of the combined Irrawaddy-Salween systems to the Indian Ocean (Robinson et al., 2007) and an analysis of carbon load and isotopic signature (Bird et al., 2008).

Arising from involvement in the international project, the thesis was devised to investigate sediment dynamics in the Irrawaddy, paying particular attention to land use change in the Lower Irrawaddy and its implications for increased sediment supply from proximal sources. The international teams were scheduled to continue work on characterizing the nature of sediment transport in the Irrawaddy at Pyay and Seitkha as well as investigating the provenance of sediment by examining variations in geochemistry along the Irrawaddy and its main tributaries. However, the impact of Cyclone Nargis in 2008, followed by increasing political instability made it unsuitable for the international team to resume its work in subsequent field seasons.

Consequently, the work reported in the thesis has been formulated as a contribution to a wider project on the source to sink sediment dynamics of the Irrawaddy; a project which is currently in abeyance while the logistics of further international cooperation is being negotiated. Some of the supporting data for the thesis which would have followed from the international project has not been possible to develop. The present study therefore concentrates on examining hydroclimatic and land use changes in the lower Irrawaddy as an area of potentially important contribution to the overall sediment budget of the basin. Unfortunately, it is not possible in the scope of the thesis to examine the nature of sediment delivery from the Upper Irrawaddy which is likely the dominant source, nor do gauging records exist on which to base estimates of relative contribution to the sediment load. Some preliminary fieldwork was conducted to collect sediment samples throughout the Irrawaddy basin but due to time constraints, the analysis of those samples is beyond the scope of the current work. Instead, the thesis concentrates on the Lower Irrawaddy and addresses the following aims:

1. To assess the nature of land use change in the Lower Irrawaddy and its implications for sediment delivery to the river.
2. To collate and examine available data on hydroclimatic variability and to assess the evidence for recent environmental change.
3. To combine the land use and hydroclimatic data in a GIS environment to investigate the potential impact of climate and human impact on suspended sediment flux based on the Thornes erosion model.
4. To contribute to the continued monitoring of suspended sediment and organic matter in the Irrawaddy at Pyay at different discharge conditions.
5. To use the results from the aims listed above to evaluate the suspended sediment of the Lower Irrawaddy and to comment on the sediment budget of the Irrawaddy basin.

1.3 Methodological Framework

The research consists of five stages. The project has involved the collection of maps, documents and data to provide background context on physical characteristics and socio economic environment of the basin. Firstly, hydro-climatic change in the Irrawaddy basin is conducted to investigate rainfall variability and an overview of water discharge and sedimentation. Secondly, land use and land cover change and time series analysis have been undertaken using RS and GIS technologies. Thirdly, a soil erosion model has been constructed to permit erosion rate estimation in relation to climatic data inputs. This model has been simulated in a selected area of the lower Irrawaddy basin. Fourthly, experimental field study of sediment discharge measurement, water sampling and geo-sediment sampling have been carried out in the study area. Fifthly, sediment analysis and geo-chemical testing in laboratory has been undertaken. Finally, the analysis is used to provide information about sources of sediment, sediment flux and impacts of climate and land use and land cover change in lower Irrawaddy basin (Figure1.1).

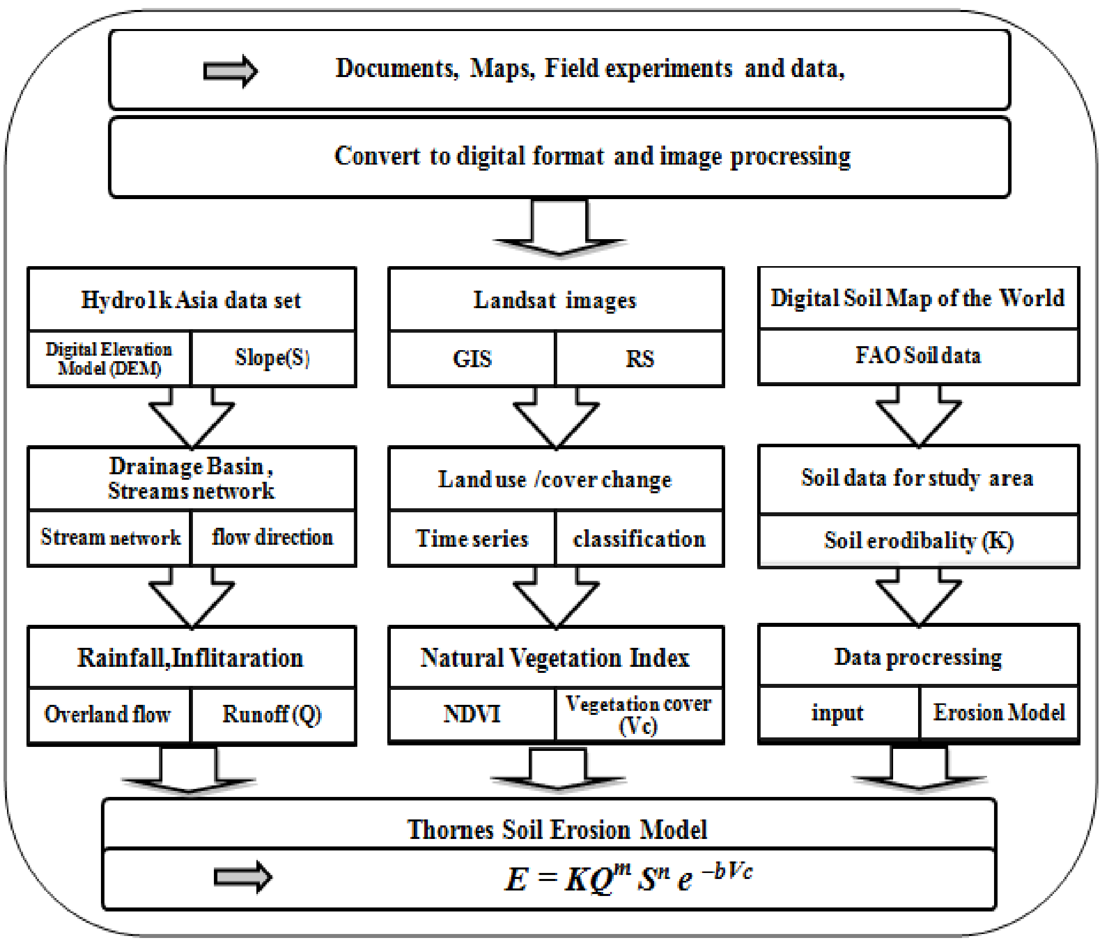


Figure 1.1 Framework of data acqiuisition and methodology

1. 4 Arrangement and structure of the Thesis

The main contents of each chapter of this thesis are as follows:

- Chapter 1 explains about the research plan and the objectives of this research are introduced in this chapter.
- Chapter 2 presents the physical factors affecting the Irrawaddy Basin and its problems about climate, land use change, water discharge and suspended sediment flux change in study area.
- Chapter 3 contains the review of the relevant literature informing research design.
- Chapter 4 examines current hydro-climatic conditions in the Lower Irrawaddy basin. Statistical rainfall analysis is conducted and a review of the impact of ENSO events on monsoon rainfall is given. The chapter also discusses changes of water discharge and sediment flux indicated by revisiting monitoring data collected in the nineteenth century. Contemporary measurements of sediment loads are also presented.
- Chapter 5 establishes land use and land cover change in the study area based on satellite images and classification over four dates (1989, 1999, 2003 and 2010).
- Chapter 6 builds up a soil erosion model based on the Thornes model. The model is simulated with varying climate and land use factors in order to identify source areas of sediment. Watershed delineation of the Lower Irrawaddy basin is developed and the SCS-CN method is applied to estimate runoff analysis. Vegetation change based on NDVI change detection analysis is conducted for the periods 1989 to 2010.

- Chapter 7 discusses the analysis of water discharge and sediment flux to the sources of sediment budget and sediment dynamics in lower Irrawaddy basin. Changes in monthly water and sediment discharge based on gauging station and water sampling and field measurement are analyzed and the impact of land use change on sediment dynamic in the lower Irrawaddy basin is discussed.
- Chapter 8 summarizes findings on sediment flux and impacts of human activity and climate factors. Here, an overview and limitations of the study are discussed and a proposal for further study of sediment geochemistry through laboratory work is elaborated.

2. STUDY AREA

2.1 Physical characteristics of the Irrawaddy Basin

2.1.1 The Irrawaddy River

The Irrawaddy River (local name: Ayeyarwady) is one of the great rivers in Asia. It is the most important commercial waterway of Myanmar with a length of 2170 km and drains an area of about 413,710 km^2 (Nyi, 1967). The headwaters originate in the eastern syntaxis of the Himalayas and Tibetan Plateau and the average discharge is 13,000 m^3/s delivering water and sediment into the Andaman Sea. The Irrawaddy basin is located between latitudes 9°30' N and 28°31' N and longitude 92°10' E and 101° 11'E (Figure 2.1). The basin is almost entirely within the territory of Myanmar with a small portion in China.

The Irrawaddy is the name given to the main stem downstream from the confluence of the two large tributaries of the Nmai Hka and the Mali Hka, approximately 18 km north of Myitkyina. The upper basin is surrounded by mountains on all sides rising to an elevation of about 5900 m above sea level. The north-south direction of Myanmar's mountain ranges is reflected in the flow of its major rivers. Almost all rivers in Myanmar flow in a north to south direction. The Irrawaddy flows from the northern highest mountains to the southern plain through the delta area and the Bay of Bengal and into Andaman Sea. Myanmar has a very long coastline of 2234 km along the Bay of Bengal and the Andaman Sea. The Irrawaddy River is the fifth largest river in the world in terms of sediment discharge. As mentioned in the introductory chapter, the conventional value for the sediment load which has been repeated in several compilations of global sediment yield is 265 MT per year, but recent studies suggest this is underestimated and that the sediment load is in excess of 300 MT and as much as 360 MT (Rao et al., 2005; Robinson et al., 2007; Furuchi et al., 2009).

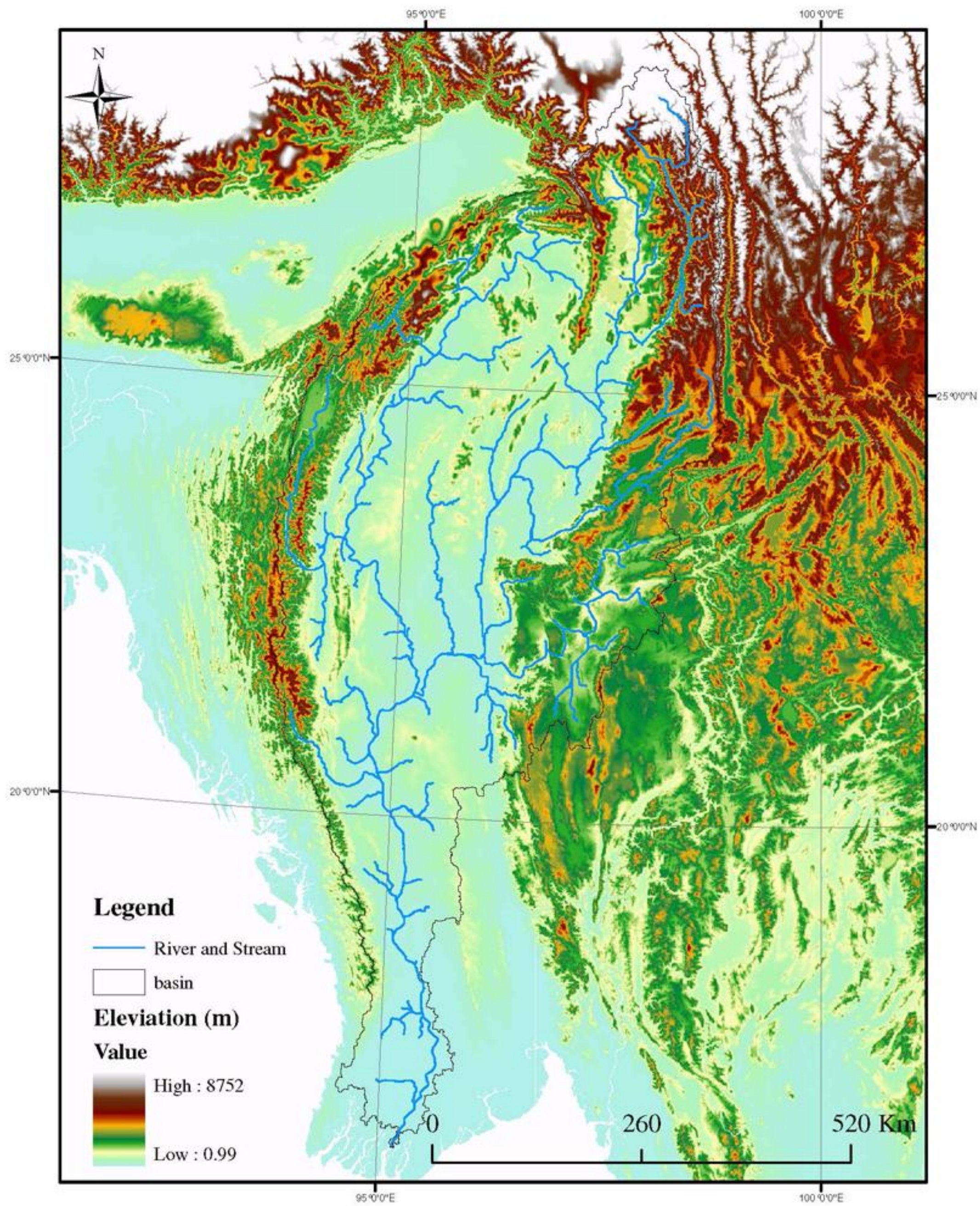


Figure 2.1 Physical features of the Irrawaddy basin in Myanmar

The Irrawaddy basin in Myanmar is conventionally divided into units which include the Upper Irrawaddy (centred on Sagaing) at 193,000 km^2 and the Central basin and Lower Irrawaddy basin at 95,000 km^2 (DWIR, 1995). This study of the Lower Irrawaddy basin (centered on Pyay) extends between latitudes 16˚ 57′ to 20˚ 47′ and from longitude 94˚ 15′ to 95˚ 52′. It lies in the transitional zone between the Central Myanmar to the north and the humid Irrawaddy Delta region to the south (Figure 2.2). It has an area of 39962 km^2 and includes twelve sub-basins. From a physical point of view the study area is situated between the Bago Yoma ranges in the east and Rakhine Yoma Mountains in the west. It is about 180 km from the Gulf of Martaban. The Chindwin River and several smaller tributaries flow into the Irrawaddy in the Upper Irrawaddy basin. Further south, several smaller tributaries streams join the Irrawaddy River. In the Lower Irrawaddy Basin, the prominent tributaries are the Yaw, Salin, Mon, Man and Mindon from the west (right bank) and the Pin, Daungthay and Yin from the east (left bank). The Nawin River joins the Irrawaddy near Pyay. The study area of the Lower Irrawaddy basin has a gauging station at Pyay, which is located about 1200 km downstream of Myitkina. The station is currently operated by the Meteorology and Hydrology Department.

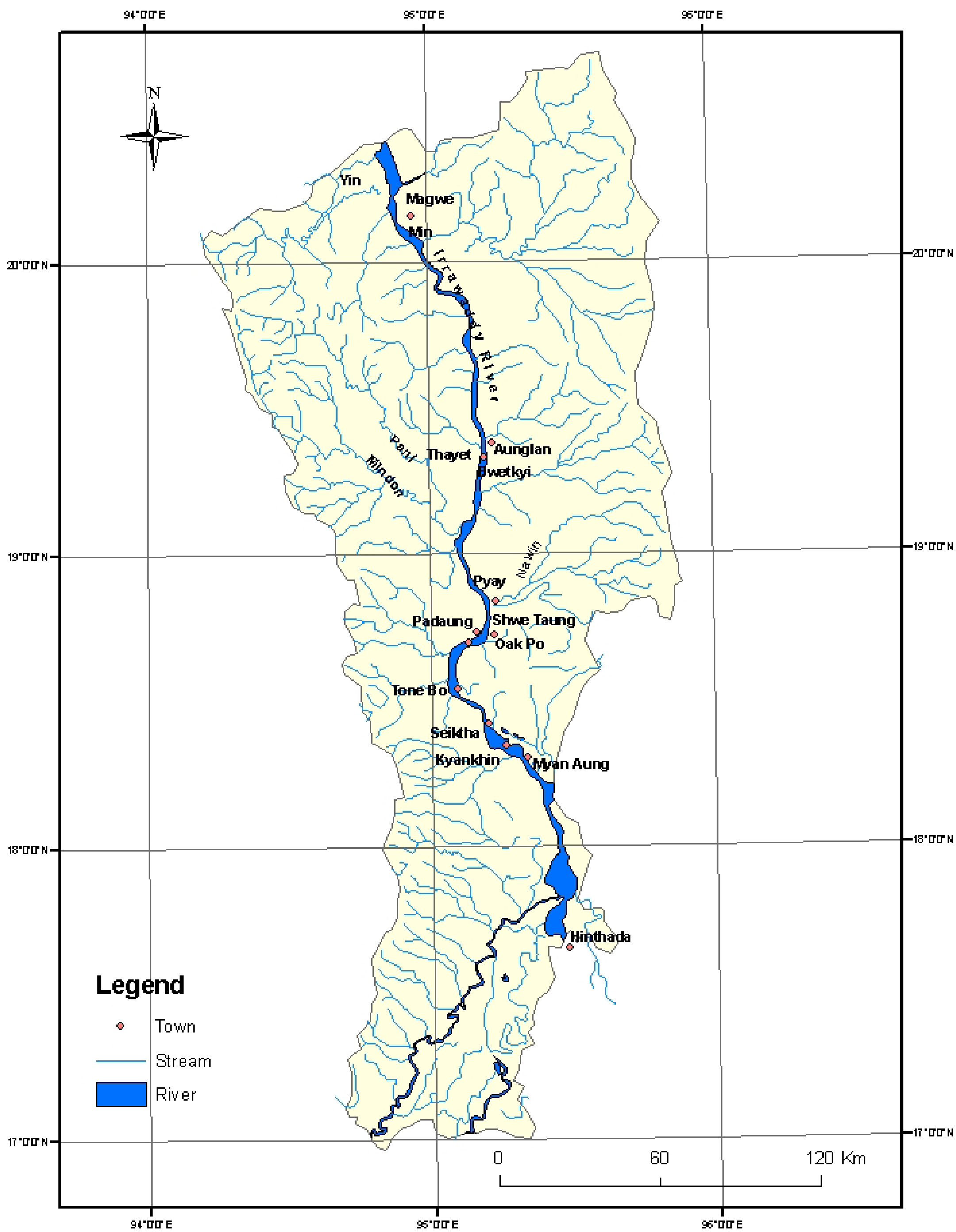


Figure 2.2 Location of the Lower Irrawaddy basin

2.1.2 Tectonic Structure

Within Myanmar there is a clear correlation between topography, geology, climate, soil and natural vegetation. Figure 2.3 shows the tectonic structure of Myanmar and figure 2.4 shows the topography of lower basin including study sites of Pyay and Seiktha. The basin is generally flat in the central part and the elevation varies from1 to 1351 m. Myanmar consists of several tectono - stratigraphic terrain types which now form the continental Mainland of the South-East Asia. Myanmar can be subdivided into six north-south trending tectonic domains. From west to east these domains are: (1) the Arakan (Rakhine) Coastal Strip as an ensimatic fore deep; (2) the Indo- Buraman Ranges as occurred arc or core (3) the Western Inner-Burma Tertiary Basin as an inter-arc basin, (4) the Central Volcanic Belt (central volcanic line) as an inner magmatic-volcanic arc; (5) the Eastern Inner-Burma Tertiary Basin as back-arc basin and (6) The Sino-Burma Ranges or Shan-Tenasserim Massif as an ensialic continental region (Regional Geology of Myanmar, 2010 and Morley C.K , 2002).

The Sagaing Transform Fault is a tectonically significant boundary between the Eastern-Burma Basin and the continental ensialic Sino-Burma Ranges. Figure 2.5 shows the regional geological features of Myanmar. The Irrawaddy basin is dominated by mixed hard and soft rocks. There are small deposits of sandstone, shale, limestone and conglomerate formed in upper Miocene and Pliocene Irrawaddy deposits group, which provides evidence of the palaeo-Irrawaddy(Maung Thein, 2000). The Fault cuts across the middle of Myanmar at Latitude 19.3°N and Longitude 96.3 E° in North to South direction. The geomorphic features reflect the underlying rock types and structure. The four Tectonic provinces of Shan- Thanintharye block, Central Cenozoic block, Western fold belt and Rakhine coastal belt differ in physiography from one another but also in geological ages and structures.

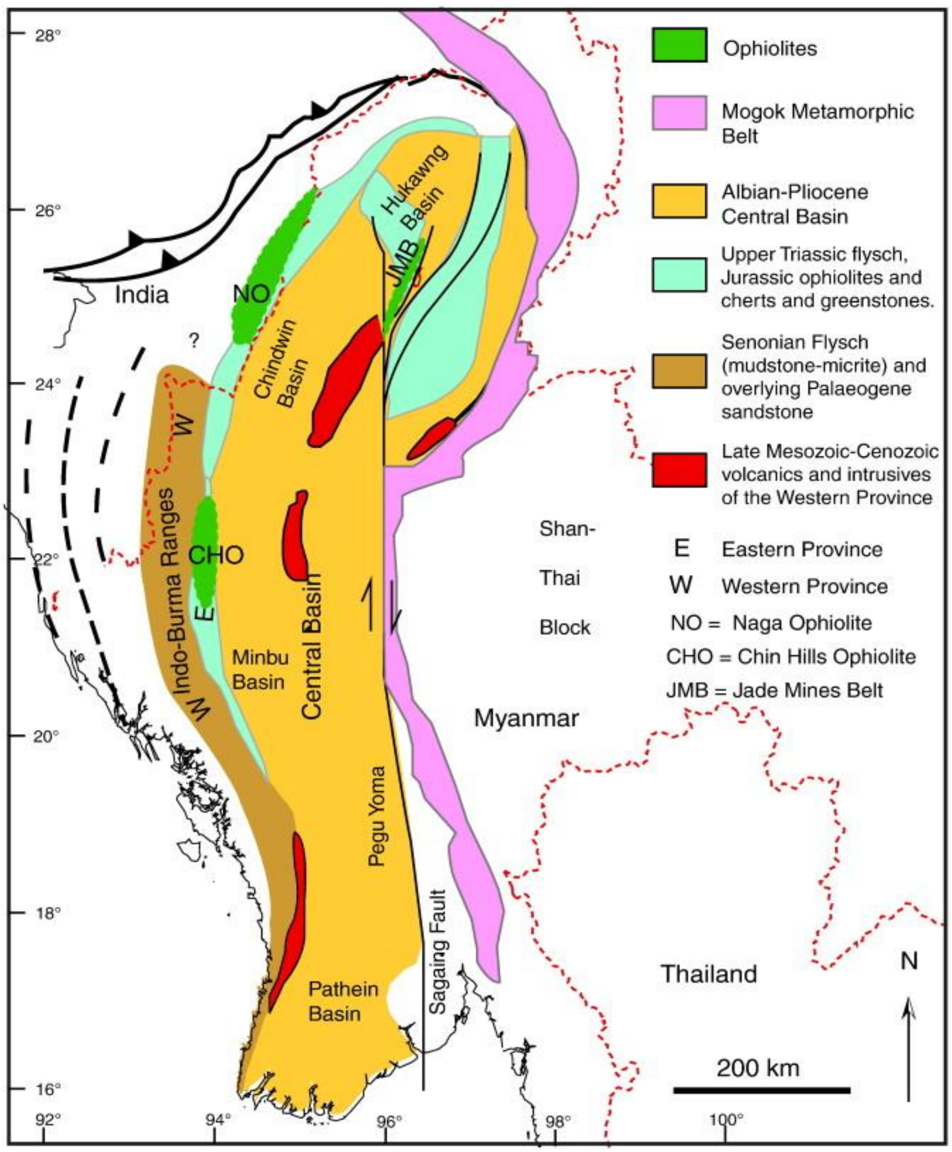


Figure 2.3 Tectonic domains and Sagaing Fault of Myanmar

Source: Morley, C.K. 2002: A tectonic model for the Tertiary evolution of strike-slip faults and rift basins in SE Asia

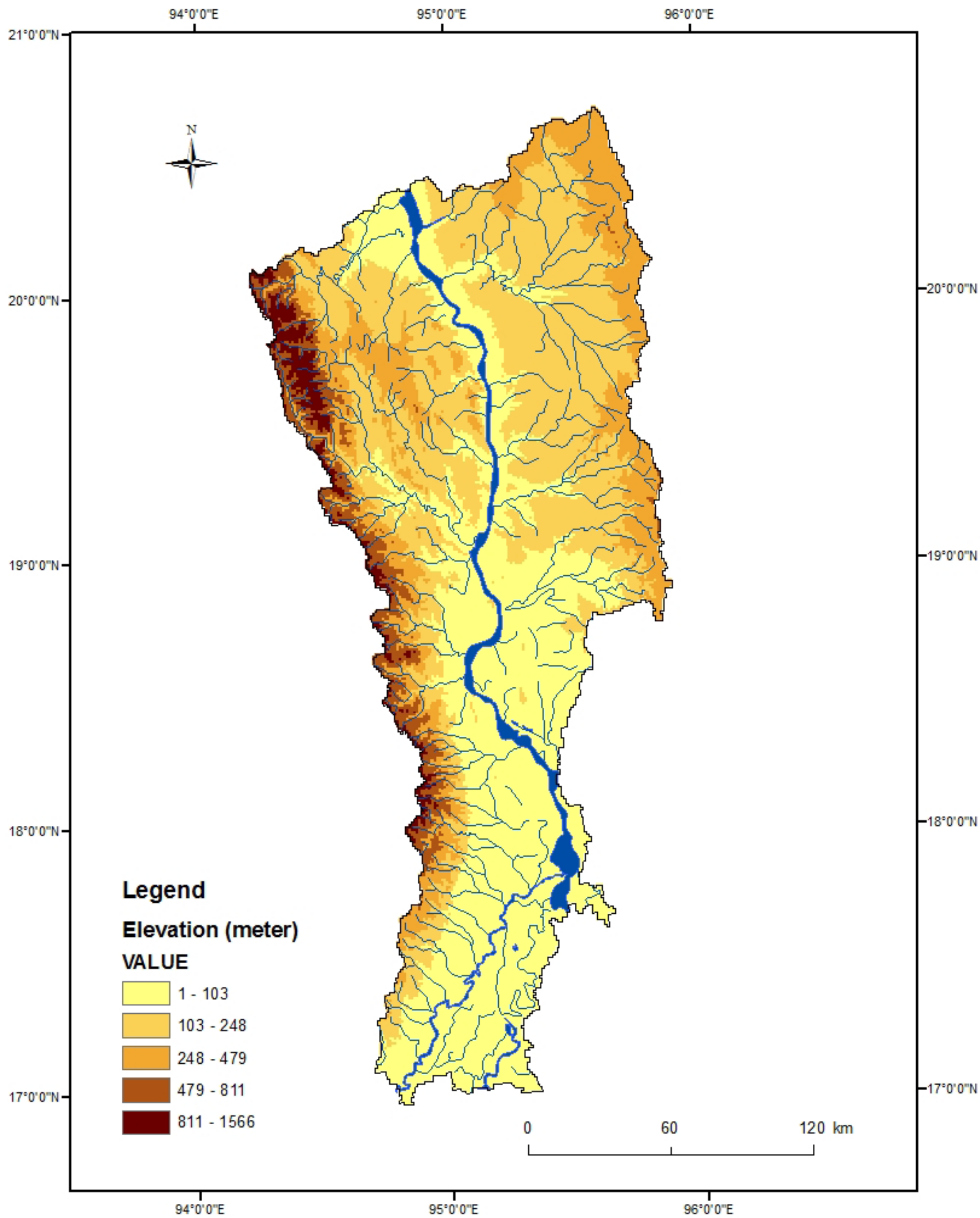


Figure 2.4 Topography of the Lower Irrawaddy basin

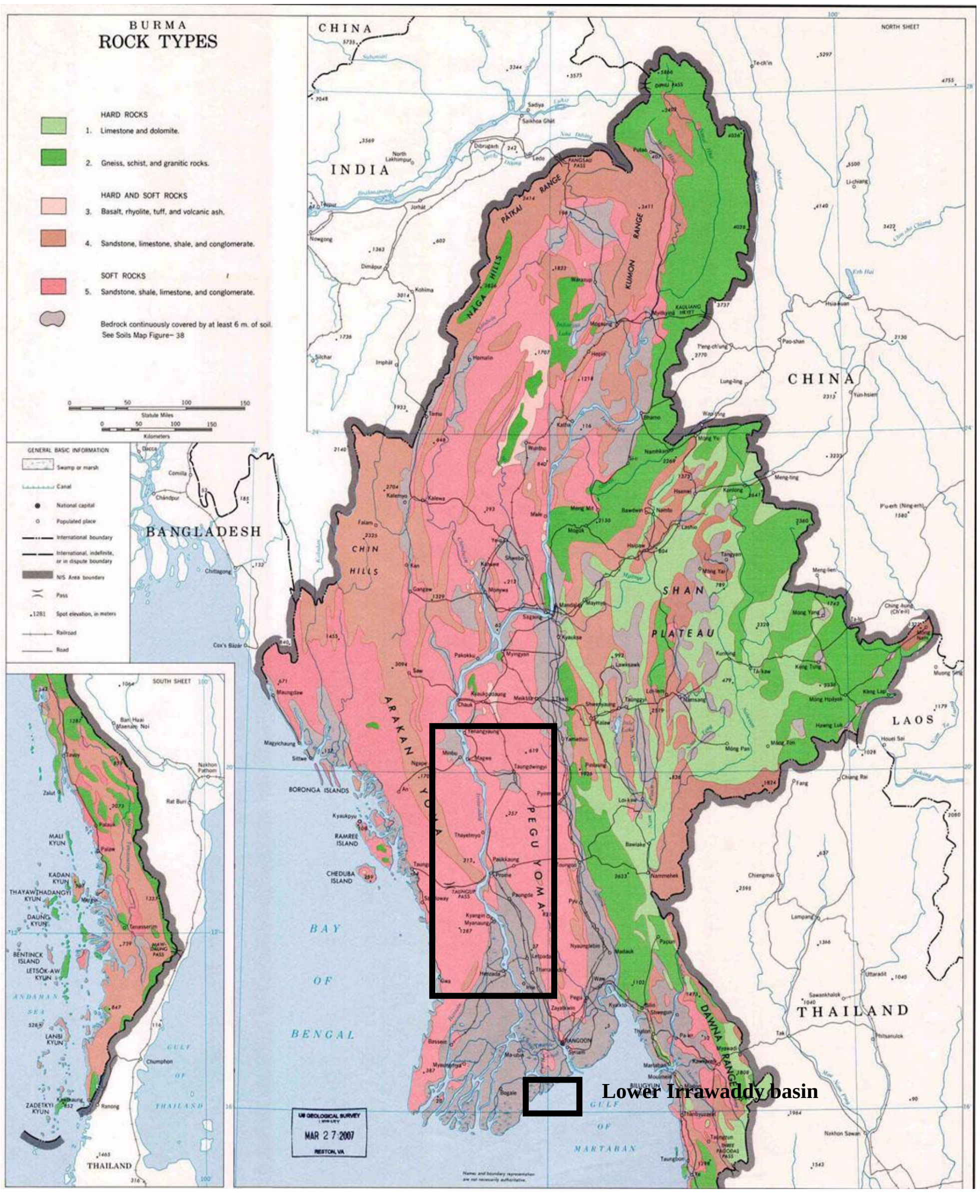


Figure 2.5 Geology of Myanmar (Rock Types)

Source: http://mappery.com/map-of/Myanmar-Burma-Rock-Types-Map,
US Geological Survey Library, MAR 27, 2007, Reston, VA

2.1.3 Geology of Lower Irrawaddy basin

The Lower Irrawaddy basin is located between the Central Tertiary Basin and Rakhine Yoma (folded mountain). The Pegu Group describes rocks found in the lowland region. The mountain ranges on the western part of the study area comprise Cretaceous and Eocene rock units trending from north to south (Bender, 1983). The rock units in the study area are as follows;

(1) Ultrabasic and Basic Intrusive: The outcrops expose patches of inter bedded Cretaceous and Eocene instrusive rocks in the southern part of Pyay. There are related to volcanic mountain belt of Central Myanmar.

(2) Flysch and Limestone: These rocks are exposed in the Rakhine Yoma and Central Chin Ranges. They are composed of shale and sandstone units. Sometimes conglomerate and limestones are mixed within these units.

(3) Pegu Group: The group is divided into Upper and Lower Pegu Group. Lower Pegu Group is Oligocene and Miocene occurring in the lowland region of eastern part of the study area and the hilly region in the northwest part of the study area. Flysch rocks are found on western part of Rakhine Yoma. These two types of rocks are interbedded flysch and limestone of Cretaceous age. They are composed of sand stone, shale and grit rock. Shellfish and clam fossils are common in sandstone. The Lower Pegu Group includes Eocene age rocks which outcrop in the central part of Irrawaddy basin. They are composed of sand, silt and conglomerates. There is an unconformity between this unit and Upper Pegu Group. Eocene rocks are found in the southern part of the Lower

Irrawaddy basin. Shale and grey wackes are found as thin layers in limestone units. Limestone is composed of shallow sea and deep sea units.

(4) Alluvium: Alluvium is widespread around the banks of Irrawaddy River in the study area, composed of recently deposited sediments. There is an unconformity between this unit and the Pegu Group.

2.1.4 Structures of folds, faults and unconformities in Lower Irrawaddy basin

(i) Folds: Anticlinal folds and synclinal folds occur in the Pegu Group in the northeastern part of the Lower Irrawaddy basin.

(ii) Faults: Faults are trended north-south, and northwest to southeast direction in the study area. East-West trending faults are found in the Pegu Group in the northeastern part of study area.

2.2 Climate in the Lower Irrawaddy basin

Myanmar has a tropical monsoon climate with a short colder season and a long hot season. High latitudes, high altitudes and continental locations in northern Myanmar (Upper Irrawaddy River) experience lower temperatures reaching freezing point in December and January. The temperature may reach the highest in Central Myanmar with average daily maxima ranging between 30°C to 40°C. Average annual temperature of Irrawaddy basin is above 20°C in the all sub-areas of the tropical zone. Precipitation in the rainy season starts with the southwest monsoon towards the end of May and continues until October. During the rainy season, the southwest monsoon winds impinge on the western mountains and the coastal ranges to produce heavy rain. In the coastal regions of Rakhine Yoma and the Tanintharyi over 5000 mm per annum are recorded. Annual precipitation varies between 850 mm to 2600 mm in the sub-basin area. In the Lower Irrawaddy basin, the southern part of the basin experiences heavy monsoon rainfall and rivers carry large amounts of sediment associated with flash floods (Figure 2.6, Table 2.1).

The monsoon precipitation plays an important role in agricultural sector in Myanmar. Nearly 70% of annual rainfall over most parts of Myanmar is received during June to September. The annual rainfall occurs primarily during the season of the southwest monsoon. River floods in Myanmar can be due to heavy rainfall from cyclonic storm crossing over the coastal area and entering the central area of Myanmar during pre-monsoon and post-monsoon season. There are a few flood records for Pyay station from the Department of Meteorology and Hydrology. Most of the tropical cyclones originate in the Southern Andaman Sea and enter the Bay of Bengal. Sometimes, tropical cyclones and storms strike from Bay of Bengal and cross over central part of Myanmar. Examples are (i) Cyclone Mala, 29 April 2006 was a very severe Cyclonic storm category 4 which affected Myanmar and northern Thailand (ii) Cyclone Nargis, 2 May 2008.

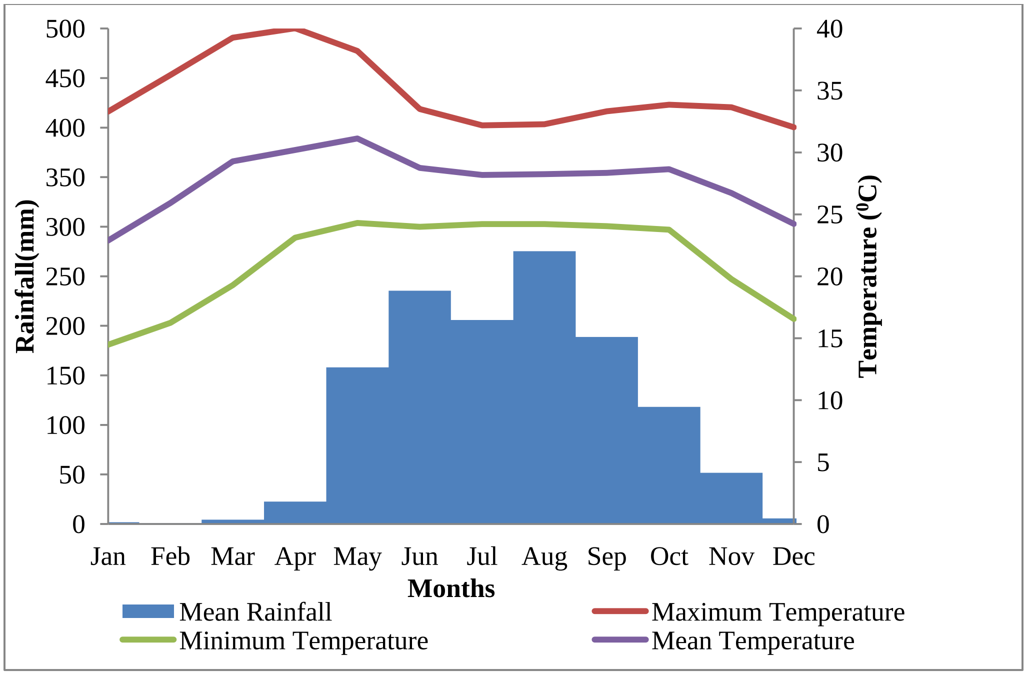


Figure 2.6 Rainfall and Temperature regimes in the Lower Irrawaddy basin (Pyay Station)

Table 2.1 Annual Temperature and Rainfall in Lower Irrawaddy basin, Pyay Station (1971-2007)

Month	Max Temperature(°C)	Min Temperature(°C)	Mean Temperature(°C)	Mean Rainfall (mm)
Jan	33.3	14.5	22.9	1.8
Feb	36.3	16.2	25.9	0.8
Mar	39.3	19.3	29.3	4.4
Apr	40.0	23.1	30.2	22.7
May	38.2	24.3	31.1	158.1
Jun	33.5	24.0	28.8	235.4
Jul	32.2	24.2	28.2	205.9
Aug	32.3	24.2	28.3	275.4
Sep	33.3	24.1	28.4	188.8
Oct	33.9	23.8	28.6	118.2
Nov	33.6	19.8	26.7	51.7
Dec	32.0	16.6	24.2	5.7
Mean	34.8	21.2	27.7	105.7

Max =Maximum Temperature (^{0}C)
Min =Minimum Temperature (^{0}C)

Source: Department of Meteorology and Hydrology, Myanmar.

Myanmar is one of the most disaster-prone countries in the world. Most of the disasters occurring in Myanmar concern weather conditions. The frequency and intensity depends on season. Annually, storm, flood, drought, earthquake and other disasters cause heavy causalities and widespread damage to property and infrastructure.

2.3 Social and economic environment of the basin

The Lower Irrawaddy basin consists of parts of three administrative divisions: the southern part of Magway Division, the western part of Bago Division and the northern part of Ayeyarwady Division. According to the General Administration Department of Myanmar, the population in 2009 for these divisions is as follows: Magway (3,759,490); Bago (4,515,201) and Ayeyarwady 5,842,093. The population density in the Lower Irrawaddy basin has gradually increased. According to the 2008 Statistical Year Book of Myanmar, the population density of Magway Division was 72 persons per km^2 in 1983 and 120 persons per km^2 in 2007. The population density of Bago Division increased from 96 to 146 persons per km^2 over the same period. The population density of Ayeyarwady Division increased from 142 to 224 persons per km^2. Population density and distribution influences physical processes and economic conditions. Most of the western part of the study area is occupied by Rakhine Yoma Mountain and its spurs. The settlements of town and villages are situated mainly on the Irrawaddy River bank. This study area is mostly occupied by mixed forest, agricultural land and barren land (it includes mixed thin soil, sand and rock and sand dunes). Seasonal crops plantations are found in floodplain area of Irrawaddy River basin in summer season. The agricultural products produced in this area comprise approximately 40% of the total agricultural sector of Myanmar. Land use change is mainly caused by the expansion of agricultural land, urban and rural settlement and other related removal of vegetation. These factors have implications for environmental degradation in the form of soil erosion and decreasing water quality. The socio-economic factors and physical factors may contribute to soil erosion and sedimentation in Lower Irrawaddy basin.

As Myanmar has agriculturally based economy the geographical limits of suitable agricultural land imposes constraints on development. The expansion of agricultural land area is facing enormous pressures from various types of environmental degradation. Land use activities, primarily for agricultural expansion and rapid urbanization in the past several decades have been widespread in the Irrawaddy basin. The severity of soil erosion in the Irrawaddy basin is the result of the past and present agricultural activities, rainfall and vegetative cover. Some of the farming practices within the area increase erosion because cultivation of cereal crops. The population of Myanmar has increased from 4-5 million (1870s) to ~59.12 million (2009s) (Ministry of Immigration and Population, Myanmar, 2010). Forest land has gradually decreased from human and natural impacts. Such changes lead to environmental degradation through soil erosion and sediment and nutrient loss into the river basins. Increase in population density, type and the use of land and climatic conditions of an area are few of the major driving forces to cause change in Land use /land cover changes (LUCC). The fact that the study area lies within the lower basin, where population density is relatively high, and the fact that the agricultural land is expending for most areas, makes it more vulnerable to faster LUCC changes. Knowledge of the distribution and types of Land use/ cover change are believed to be important indicators for resource base analysis with regard to land degradation and productivity, hence problems or possibilities for land development. That could be possible by examining the changes in distribution and types of Land use /cover change in the past, and also those future predictions will be possible. Land use /cover change has impact on hydrological processes, soil erosion, runoff and sedimentation and sediment delivery. In order to understand the historical and contemporary linkages between Land use/ cover change and its resulting effects on hydrology and geomorphology and other systems, it will be necessary to make significant advances in documenting the rates and causes of Land use / cover change. Our current understanding of historic Land use/ cover change in Irrawaddy River basin of Myanmar is not adequate.

2.4 Sediment problem of the Irrawaddy basin

High rates of soil erosion and sediment delivery contribute to a sedimentation problem throughout the Irrawaddy River Basin. However, relatively little is known about sediment delivery dynamics, but it is extremely important for river ecology, sediment dynamics and nutrient transport. The sediment budget has broad effects upon several processes of soil erosion in the Irrawaddy River Basin which are of serious concern. The sediment load may be increased by natural and human impacts. Land use activities, primarily for agricultural expansion and rapid urbanization in the past several decades have been widespread in the Irrawaddy basins. The population of Myanmar has increased from 4-5 million (1870s) to ~59.12 million (2009s) and forest land has decreased from 274150 km^2 to 182060 km$^{2.}$ Such changes lead to environmental degradation through soil erosion and sediment and nutrient loss into the river basins. Milliman and Syvitski (1992) explored the causes behind variations in amount of sediment released to coastal waters and concluded that the large rivers in Asia carry ~30% of the total suspended load that reaches the global oceans. About 20 % of the total flux of water, sediment, and dissolved load from the Himalayas and Tibet to the ocean should be attributed to the Irrawaddy River (Milliman and Meade 1983 and Syvitski et al., 2003). In a more recent study, based Department of Meteorology and Hydrology, the suspended sediment load of Irrawaddy River basin was estimated at $325 \pm 57 \times 10^6$ t/year (Furuichi et al., 2009). A field study on modern discharge and sediment load measurements suggests that the original 19th century data underestimated the actual sediment load. Robinson et al. (2007) suggest the sediment load is $364 \pm 60 \times 10^6$ t/year. Previous research undertaken by the author with others included field measurements of sediment fluxes during the onset of 2005 and 2006 monsoon seasons on the Irrawaddy River. Quantifying the Sediment budget requires a clear understanding of sediment dynamics in Irrawaddy River drainage basin. The relationship between land use, erosion, and sedimentation is not clear. There have been a few studies on land use change in Myanmar but, linking these to sediment dynamics has not been done. The approach to this study is physically based on quantifying sediment delivery in river using the framework for the empirical and conceptual modelling techniques need to involve for sediment budget. However, the information and datasets with GIS and RS modeling techniques are useful for studying the large scale Irrawaddy basin. Further research of field studies needed to measure the sediment concentrations and characteristic of the water and sediment geochemistry along the length of the River to discriminate the sources of sediment for the river system.

Irrawaddy River basin has been affected by severe soil erosion which contributes to a high sediment load. An improved understanding of spatially variable sediment flux source to sink and sediment budgets provides a platform to analyze the impacts of environmental changes. This study of sediment budget analysis and sediment source and sink in the Irrawaddy basin in Myanmar is very important. This may be useful for water resource and river management and socio-economic planning and future water and sediment projects.

Soil erosion is an important environmental problem in the world today because it threatens agriculture and generates water quality concerns. It becomes an acute problem when human activity causes rapid soil degradation. Water erosion generally occurs on slopes during the rainy season in the study area. The main factors influencing soil erosion include climate (rainfall and wind), landscape relief, soil and bedrock properties, vegetation cover and human activities of land use/cover change. Examples of erosion within the study area are shown in Figure 2.7. Sediment yield increases with increasing annual rainfall and drainage basin slope and its magnitude depends upon the nature of surface material. The river discharge and sediment load reflect the composite of the entire river catchment while rainfall serves as one of the major input into the runoff processes. Human impacts of land use/cover change and differences in vegetation cover and surface slope may also influence the soil erosion level. Predicting the sediment discharge of river requires the knowledge of soil erosion and sedimentation throughout river basins. Suspended sediment concentrations vary widely throughout different geomorphological classes of rivers, streams, channels and tributaries.

Figure 2.7 Examples of soil erosion in the study area

3. LITERATURE REVIEW

This chapter provides a review of the relevant literature concerning hydroclimatic changes, land use and land cover changes, modelling soil erosion and monitoring for discharge and suspended sediment flux in the Irrawaddy River.

3.1 Hydroclimatic changes in the basin

The word “Monsoon” derived from Arabic word meaning ‘seasons’ and it is a term most often applied to describe the seasonal reversal of wind direction and persisting precipitation along the shores of the Indian Ocean (Webster et al., 1987). The South Asian summer monsoon is part of an annually reversing wind system. A monsoon system is characterized by a seasonal reversal of prevailing wind directions and by alternating wet and dry seasons. In India and South Asia the wet season, called the southwest monsoon, occurs from about mid-June to early October, when winds from the Indian Ocean carry moist air across to the subcontinent, cause heavy rainfall and often storms and cyclones. There have been some specific references in the literature to the monsoon climate and rainfall in Myanmar, which are discussed below and it is highly complex. Rainfall over South Asia is predominantly due to the summer and winter monsoon systems, associated with cyclonic storms and other atmosphere disturbances traversing certain parts of the region, also during the west monsoon. Extreme weather or climate events can have major impacts on society, the economy and the environment (Karl et al., 1999). In the nineteenth century, numerous climatological studies were conducted on the Indian monsoon and south west monsoon over South Asia countries. A systematic study of variability of annual rainfall and draughts over South Asia was made by Blanford

(1886) for British India (the whole country as one unit, including the present Pakistan, Sri Lanka, Bangladesh and Myanmar). He computed the areal mean annual rainfall during 1867-85 based on a varying network of about 500 rain gauges, and found that the mean annual rainfall of British India ranged from 900 mm in 1868 to 1240 mm in 1878. Later, Walker (1923) estimated the country-wide mean summer Monsoon (June to September) rainfall of India. For about 50 years following Walker's efforts, very little work was done on a comprehensive analysis of Indian summer monsoon rainfall. The main Southwest monsoon air mass affecting continental SE Asia does, however, originate in the Indian Ocean. While this air mass is weaker than that of the Northeast monsoon, the moisture is much deeper (up to 9,000 m along the Myanmar coast) and much more unstable (McGregor and Nieuwolt, 1998; Nieuwolt, 1981). In late September and October, the Asian continent begins to cool down, which weakens the Southwest monsoon. The seasonal droughts in the northern parts of SE Asia (Laos, Myanmar, Thailand, and Vietnam) introduce a much larger requirement for irrigation in these areas to sustain agriculture (Barker and Molle, 2004).

The climate impact on runoff and river behaviour influencing the shapes of river hydrographs are strongly regulated by the shape of the rain graph. The rain graph can be of equal importance to the soil and rock properties in governing these runoff processes (Robinson and Sivapalan, 1997). Thus the higher intensity of rainfall means that regions with a higher proportion of Tropical cyclonic rainfall events (e.g., Philippines, Myanmar, southern China, and southern Vietnam) are more sensitive to the hydrological effects of ground disturbance (Malmer et al., 2004; Chappell et al., 2003). Climate is key controlling factor of the regional hydrological cycle and land-surface hydrology.

The climatic variables that most strongly affect the hydrology of Southeast Asia are the precipitation and net radiation. The delivery of precipitation to the land surface is dependent on the type of storm event (e.g., cyclonic, convective, stratiform, orographic, and in the tropics) and the presence of cycles on diurnal, 30-60 day Madden-Julien Oscillation (MJO), monsoonal, 4-5 year El Niño – Southern Oscillation (ENSO), and decadal time scale (Chen and Chappell, 2009). The variability of Indian summer monsoon both from observational data and studies has identified a strong link with El Niño Southern Oscillation (ENSO). Statistical methods for forecasting the Indian monsoon rainfall use this ENSO and monsoon relationship. For example, this is having a strong impact on the forecasting efforts of Indian monsoon as most of its predictors are related to ENSO. Furthermore, Krishna Kumar et al., (1995, 1999A, B), show that the Indian monsoon predictors are strongly related to the Indian monsoon only when the monsoon itself is strongly related with ENSO. Changes in the relationship the ENSO events and tropical climate including Indian summer monsoon rainfall were established by Torrence and Webster (1999). Within the seasonal Southeast Asia tropics (notably southern China and Myanmar, Thailand and Vietnam), the absence of significant rainfall in the northern winter means that the streams and small rivers on non-aquifers have very small or no low flows. Similarly, during ENSO dry periods (El Nino years), the lack of rainfall reduces rivers low flows in non-aquifers regions (Boochabun et al., 2004).

Movement of precipitation over the Bay of Bengal, using daily, weekly, monthly and seasonal rainfall studies, will help in objectively identifying the spatial variability of monsoon rainfall. The movement of the monsoon trough from the Bay of Bengal towards Myanmar, results in a variation of climate classification of Myanmar into different areas.

Myanmar has been witnessing changing weather events in almost every year during the last two three decades. These include the onset, withdrawal, duration and intensity of monsoon, and the frequency of the monsoon depressions. (Tun Lwin, Khin and Cho Cho Shein, 2006). The changing patterns of the monsoon climatology such as later than normal onset, earlier than normal withdrawal, shorter than normal monsoon season duration during the last three decades are quite dramatic and unusual compared to the previous years. Moreover, most of the dry and hotter than normal years are also observed in recent years especially in 1980s and 1990s. It is also evident in 1980s and 1990s that annual storm frequency has been far less than normal, especially in monsoon depression frequencies in the Bay of Bengal. By using the climatologically records of Myanmar for the last five decades the changing weather events and the features of monsoon climate of Myanmar has been experienced in line with the Global Climate Change (Tun Lwin and Kyaw Lwin Oo 2006). There were no significant trends in extreme rainfall indices in Myanmar but warm nights have significantly increased in frequency (Manton et al., 2000). There have been studies on the analysis of frequency and intensity patterns of rainfall which examine the relationship between daily rainfall occurrence and amount in Indian monsoon. (Unkasevic and Radinovic., 2000). A statistical analysis of daily maximum and monthly precipitation demonstrated that they are highly correlated. The rainfall studies conducted for India by previous researchers have been primarily concentrated on the examination of rainfall series for south-west monsoon rainfall as a whole study area (Gadgil et al., 1993). Other scholars studied the relationship between rainy days and seasonal rainfall in the normal, flood and drought years over India and concluded that linear relationship fits better than logarithmic relationship. Most of the flooding in the Lower Irrawaddy basin and the delta is by the Chindwin River and when it coincides with upper Irrawaddy floods, severe flooding occurs in the delta (Khin Maung Nyunt, 2005). The study by Sen Roy and Kaur (2000) on the climatology of monsoon rains of Myanmar (Burma), has been studied from India Meteorological Department, based on 33 years rainfall data of Myanmar for the summer monsoon months (June-September) by using the rainfall distribution and coefficient of variation, different statistical characteristics of the seasonal, monthly and zonal rainfall and analysis of inter annual and intra seasonal variability and the correlation between the rainfall of different months and zones. Trend and periodicity of the rainfall series have been examined by different statistical techniques, indicating little evidence of a trend. The rainfall series of Myanmar shows little correspondence with neighboring Bangladesh and Northeast India, even though all of them are influenced by similar weather systems.

3.2 Land use and Land cover changes in the basin

Land use and land cover change have become a central component in current strategies for managing natural resources and monitoring environmental changes. Viewing the Earth from space is now crucial to the understanding of the influence of man's activities on his natural resource base over time. In situations of rapid and often unrecorded land use change, observations of the earth from space provide objective information of human utilization of the landscape. Over the past years, data from Earth sensing satellites has become vital in mapping the Earth's features and infrastructures, managing natural resources and studying environmental change. The need to conduct research on historical Land use /cover change is that by understanding the past, it could be possible to make projections for the future. As mentioned previously, among the land use changes occurring, the most significant historical change in land cover has been the expansion of agricultural lands. The term land cover originally referred to the kind and state of vegetation, such as forest or grass cover but it has broadened in subsequent usage to include other things such as human structures, soil type, biodiversity, surface and ground water (Meyer, 1999). Land use affects land cover and changes in land cover affect land use. A change in either however is not necessarily the product of the other. Changes in land cover by land use do not necessarily imply degradation of the land. However, many shifting land use patterns driven by a variety of social causes, result in land cover changes that affects biodiversity, water and radiation budgets, trace gas emissions and other processes that come together to affect climate and biosphere (Riebsame et al., 1994). Even though, natural processes may also contribute to changes in land cover, the major driving force is human induced land uses (Allen and Barnes, 1985). In order to understand the various implications of land cover change, understanding of land use change is essential. Land cover can be altered by forces other than anthropogenic. Natural events such as weather, flooding, fire, climate fluctuations, and ecosystem dynamics may also initiate modifications upon land cover. Globally, land cover today is altered principally by direct human use: by agriculture and livestock raising, forest harvesting and management and urban and suburban construction and development. A remote sensing device records response which is based on many characteristic of the land surface, including natural and artificial cover. According to de Sherbinin (2002), land use is the term that is used to describe human uses of land, or immediate actions modifying or converting land cover. Land use describes how a tract of land is used, such as residential, commercial, or industrial. Land cover is closely related to land use in that it describes the state or physical appearance of a natural land surfaces such as bare soil, woods, or grasslands (Burian et al. 2002). Land cover changes results show the natural processes such as volcanic eruptions, river channel changes and sea level. However, most of the land covers changes of the present and past decades are due to human impacts. LUCC in a catchment is referring to the natural and anthropogenic factors which influenced changes of catchment area. That can be change over time due to natural and anthropogenic causes. It is clear that land cover can affect both the degree of infiltration and runoff following rainfall events, while the degree of land cover can affect rates of evaporation. Land cover has various properties that help to regulate water flows both above and below ground.

Natural and man-made processes cause changes of catchment area on different time and space scales. Land cover change and other anthropogenic emissions are contributing towards this problem. The United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol have resulted from the recognition of man’s role in changing the climate. Changes in land use can result in the release of carbon into the atmosphere, or withdrawal of carbon from it. The catchment landscape has been increasingly altered by natural and human impacts. The effects of natural control and human activity on the catchment landscape can have a strong impact upon land and water resources both in terms of their quantity and quality. On the other hand, land cover refers to the natural vegetative cover types that characterize a particular area. Land use change is the proximate cause of land cover change. The effect of land use change on dry-season flow depends on competing processes, most notably changes in large area and infiltration capacity. The net impact is likely to be highly site-specific (Calder, 1998). In larger basins, effects of land use practices on peak flow are offset due to time lag between different tributaries, different land use and variations in rainfall (Bruijnzeel, 1990). In larger watersheds, this de-synchronisation effect can lead to a reduction in peak discharge, although overall storm flow increases due to land use changes in individual sub-watersheds (Brooks et al., 1991). The water table may rise as a result of decreased evapotranspiration, e.g. following logging or conversion of forest to grassland for grazing. Recharge may also increase due to an increased infiltration rate, e.g. through afforestation of degraded areas (Tejwani, 1993). In contrast, the water table may fall as a result of decreased soil infiltration, e.g. through non-conservational farming techniques and compaction (Tejwani, 1993). Also, heavy grazing may lead to reduced infiltration and groundwater recharge (Chomitz and Kumari, 1996).

The Land cover classification procedure involves a continental Digital Elevation Model (DEM) from which a drainage network is derived. The system for delineation and codification of basins is based upon topography and the topology of the resulting drainage network. The main stream of a river is always taken as the watercourse which drains the greater area; the tributary drains the lesser of the two areas. The area directly drained by the reach of the main stem is called an inter-basin. The area drained by a tributary is called a basin (Verdin, 1997). In Southeast Asia, high population density and agricultural activities are concentrated in the deltas, low-lying coastal areas and lower river valleys (Volker, 1983).Remote Sensing (RS) and Geographic Information System (GIS) are now providing new tools for advanced ecosystem management. The collection of remotely sensed data facilitates the synoptic analyses of Earth - system function, patterning, and change at local, regional and global scales over time; such data also provide an important link between intensive, localized ecological research and regional, national and international conservation and management of biological diversity (Wilkie and Finn, 1996). Land cover is continually moulded and transformed by land-use changes such as, for example, when a forest is converted to pasture or crop land. Land-use change is the proximate cause of land-cover change. The underlying driving forces, however, can be traced to a host of economic, technological, institutional, cultural and demographic factors. In fact, humans are increasingly being recognized as a dominant force in global environmental change (Moran 2004, Turner 2001, Lambin et al. 2001). Changes in land use are likely the most ancient of all human-induced environmental impacts, and the first type of impact which could be considered global. For example, land-cover change, especially the conversion of forested areas into other uses, has been identified as a contributing factor to climate change, accounting for 33 percent of the increase in atmospheric carbon dioxide since 1850, and a leading factor in the loss of biological diversity (Vitousek et al. 1997). Overgrazing and other agricultural practices in developing countries are causes of land degradation and desertification. Water diversion for land irrigation consumes about 70 percent of all water withdrawals and is sufficiently significant to stop the flow of such large rivers as the Colorado (US), Huang He (China), and Amu Darya (Central Asia) from reaching the sea during the dry season. Human uses of land usurp as much as 40 percent of the net primary productivity of the earth, and changes in these may alter ecosystem services locally and globally (Vitousek, et al. 1997). Land use change is driven by the interaction in space and time between biophysical and human dimensions. The potential large impact of land use/cover change on the physical and social environment has stimulated research in the understanding of land use change and its main causes and effects. Land use change models are tools for understanding the causes and consequences of land use dynamics. Scenario analysis with land use models can support land use planning and policy (Veldkamp and Lambin, 2001). Deforestation can also impact hydrological processes, leading to localized declines in rainfall, and more rapid runoff of precipitation, causing flooding and soil erosion. This dual role of humanity in both contributing to the causes and experiencing the effects of global change processes emphasizes the need for better understanding of the interaction between humans and the terrestrial environment. This need becomes more imperative as changes in land use become more rapid. Understanding the driving forces behind land-use changes and developing models to simulate these changes are essential to predicting the effects of global environmental change (Veldkamp et al., 2001). The technology of Geographic Information (GIS) and Remote sensing (RS) is a tool used to analyze the surface of the earth and to monitor changes of land use and land cover in higher accuracy and display of spatial information and geographic information of socio-economic factors.

3.3 Modelling soil erosion in a river basin

The following literature review is concentrating on the relevant topics in terms of erosion and soil erosion detection as well as the assessment of input parameters that are of interest for developing the large scale basin erosion model. Moreover, the literature review primarily focuses on the scientific literature of the last several years and developed modeling approaches. The accuracy of estimating soil loss depends on model and environmental factors. Numerous studies have been completed in an attempt to predict the fluxes of sediment from a watershed more accurately. The methods used by researchers to quantify the contributions from different source areas to a catchment vary but generally result in budget of sediment fluxes. Table 3.1 shows some of the conceptual, physical and process base soil erosion and hydrologic model reviewed.

Recent development in computer power and programming techniques are proving useful in this respect to the relative contributions from individual sediment sources (Collins et al., 2004). Most of the earlier studies using Global Digital environmental datasets and computer-based modelling have been used to examine sediment delivery to the world's oceans (Summerfield and Hulton, 1994). This work focused on comparing the sediment yield of large rivers around the world rather than the sediment budget within large river basins. From the 1990s, techniques have become available for examining sediment sources within large basins although there is some limitation with resolution and potential difficulties in calibration. There are difficulties in modeling large river basin using models developed under either physical or conceptual approaches. A conceptual model is based on simplified representations of the watershed, representing it as a network of flows within the entire catchment. The integrated approach of modeling allows for relatively easy and effective estimation of spatially distributed soil erosion and sediment delivery. It thus provides a useful and efficient tool for predicting long-term water erosion potential and assessing erosion impacts of various systems and conservation support practices.

Empirical models are limited to conditions for which they have been developed. The erosion and sediment delivery component is based on estimating the upland erosion by different streams and catchments. Physically based models are based on the solution of fundamental model of rainfall runoff formation on using different equations, which describe the processes of overland flow, ground water and channel flow and its application to the modelling of sediment transport in the catchment. Researchers have developed many predictive models that estimate soil loss and identify areas where conservation measures will have the greatest impact on reducing soil loss for soil erosion assessments (Angima et al., 2003). Soil loss due to soil erosion can be estimated using predictive models such as the main categories of empirical, conceptual and physical based models (Merrit et al., 2003). Various approaches to soil erosion modelling exist. Those approaches vary in scale, both in time and space, amount of data required, processes based model, mathematical representation of processes, and finally they also vary in the type of output. The most basic erosion models such as the Universal Soil Loss Equation (USLE) predict the gross erosion from a given area without indicating the portion of erosion leaving that area. Sediment yield, which is the portion of erosion leaving the study area, is estimated in various ways. Empirical sediment delivery ratio formulae are often combined with the USLE to estimate the sediment yield. When a spatially variable sediment delivery ratio is combined with the USLE, the effects of localized changes in input parameters on the overall sediment yield can be modeled without having the ability to produce predictions of the convoluted interactions of sediment yield at any scale that is less than the entire modeled area. This is due to the fact that sediment yield is modeled as the summation of the product of gross erosion per sub-area and the sediment delivery ratio for that same area. Sediment deposition in such models is not modeled explicitly. More complex models such as physically based models include mathematical relationships based on physical attributes of eroded material. Such models describe the dynamics of detachment, transport and deposition and produce spatially varied estimates of detachment, deposition, and sediment yield. Empirical models are simplified representations of natural processes based on empirical observations. They are based on observations of the environment and thus, are often of statistical relevance (Nearing et al., 1994). Empirical models are frequently utilized for modeling complex processes and, in the context of erosion and soil erosion, particularly useful for identifying the sources of sediments. USLE and its modifications are the examples of empirical models and ANSWER, CREAMS, and MODANSW are the samples of conceptual models. Examples for the first two groups comprise the empirical USLE and its modifications, and some of the more comprehensive models like ANSWERS, CREAMS. Physically based models represent natural processes by describing each individual physical process of the system and combining them into a complex model. Physical equations hereby describe natural processes, such as stream flow or sediment transport (Merritt et al., 2003). European Soil Erosion Models, EUROSEM/KINEROS, EUROSEM/MIKE SHE and SHESED-UK are physically-based models that have been developed at catchment or small sub-basin scales (Fistikoglu and Harmancioglu, 2002). This complex approach requires high resolution spatial and temporal input data. Physically based models are able to explain the spatial variability of most important land surface characteristics such as topography, slope, aspect, vegetation, soil, as well as climate parameters including precipitation, temperature and evaporation (Legesse et al., 2003).

Conceptual models are a mixture of empirical and physically based models and their application is therefore more applicable to answer general questions (Beck, 1987). These models usually incorporate general descriptions of catchment processes without specifying process interactions that would require very detailed catchment information (Merritt et al., 2003). These models therefore provide an indication of quantitative and qualitative processes within a watershed. Some of the empirical and conceptual models are The Sediment Delivery Distributed model (SEDD) ,The Agricultural Non-Point Source pollution model (AGNPS), The Large Scale Catchment Model (LASCAM) and USLE model.

Physically based models are Area Non-Point Source Watershed Environment Response Simulation Model **(**ANSWERS**)** (Beasley et al.,1980), Chemical Runoff and Erosion from Agricultural Management Systems (CREAMS) (Knisel,1980), European Soil Erosion Model (EUROSEM),(Morgan et al.,1991,1992), Kinematic Erosion Simulation Model (KINEROS)(Smith et al., 1984), Erosion Productivity Impact Calculator(EPIC) (Williams et al., 1984,1995). The Generalized Sediment Transport models for Alluvial Rivers (GSTAR) have been used by many organizations and universities around the world for engineering, research, and teaching purposes (Yang et al., 2004). Commonly used erosion and soil erosion models developed in the last decades tend to shift in their methodology from empirical and conceptual in the 1970s to physically based and conceptual approaches in the present. Various sediment transport model (i.e. one, two and three dimensional by Lin et al., 1983) have been developed in the hope of future understanding the dynamic nature of the SSC profile in rivers. The simulating of the real environment is sensitive to input parameter. There are difficulties in modeling large catchments using models developed under either of these approaches. A conceptual model is based on simplified representations of the watershed, representing it as a network of reservoirs within the entire catchment. An empirical model is a model for which parameters have already been calibrated, and is usually statistical. These types of models focus on modelling the structural relationship between the watershed inputs and the outputs. Compared to an empirically based model, a conceptual model has more physical information and an increasing complexity in the relationships that define the watershed. The integrated approach of modeling allows for relatively easy, fast, and cost-effective estimation of spatially distributed soil erosion and sediment delivery. It thus provides a useful and efficient tool for predicting long-term water erosion potential and assessing erosion impacts of various cropping systems and conservation support practices. Empirical models are limited to conditions for which they have been developed. The erosion and sediment delivery component is based on estimating the upland erosion by vary of the streams, watershed and basin (Chakrapani, 2005).

The sediment yields of the major rivers of the world have been estimated (Holeman, 1968). They range from more than 7000 t /km^{-2} year^{-1} for tributaries of the Yellow River in China (420- 490 t km^{-2} year^{-1}) for the Yangtze, Indus, and Mekong to less than 100 t km^{-2} year^{-1} for the Mississippi, Amazon, and Nile. In Europe the suspended sediment yield of the USSR, Rhine, Holland, Loire, France; and Oder, Poland all are less than 3.5 t km^{-2} year^{-1}. Projects under the IHP and the IAHS International Commission on Continental Erosion are presently extending the evaluation of delivery of global river sediments to the oceans. Problems associated with high erosion rates are particularly evident in high mountainous regions, given a combination of high relief, extreme weather conditions, climate change and resource development (Jain et al., 2001; Yang et al., 2003). The large quantity of sediment eroded and transported downstream creates a number of major water resources management problems such as siltation of reservoirs, damage to turbines, reduction in quality of water supplies, and transport of chemical pollutants. As a result, there is a continuing need for a better quantitative estimation of erosion processes, rates, patterns, and their response to environmental change (Walling and Webb, 1996). Relationships between sediment yield and its controlling variables have been investigated at global and regional scales through correlation and regression analysis by Lu and Higgitt (1999). The most fundamental parameter is the settling velocity (Hill et al., 1998, You and Lange 1995) which is often derived empirical and typically assumed to be constant through time. Erosion is calculated as a function of the indicators of driving forces (e.g. runoff rate and gradient) and resistance to erosion (e.g. soil properties and vegetation cover). The sequences of sediment data with modelling and testing spatially distributed sediment budgets to relate erosion processes to sediment yield studies carried out for large river basins (Chavoshain et al., 2007,Wilkinson et al., 2009; Xu 2008). Soil erosion is calculated using the equation of Thornes (1985, 1990) and is a function of slope, surface runoff volume and vegetation cover. This is a delivery limited model which takes no account of sediment supply dynamics. It does not simulate sediment deposition, only erosion and is thus rather limited but is nevertheless applicable at the scale and resolution used here since its data requirements are much less than most sediment dynamics models (Thornes 1976, 1989, 1994, 1996, 2000). Spatially distributed erosion rate and sediment load can be predicted in the Irrawaddy basins with soil erosion and sediment delivery model. Potential erosion rates can be calculated with the Thornes model in combination with a surface runoff model. Spatial sediment delivery is analyzed through pre-processing by GIS, calculation of sediment delivery, post-processing and display of spatial output in the GIS. Sediment yield delivery is a function of travel time of surface runoff from catchment cells to the nearest downstream channel.

Thornes (1985, 1990) developed a conceptual erosion model that contains a hydrological component based on a runoff storage type analogy, a sediment transport component and a vegetation cover component. The Thornes erosion model is selected for this study because the model requires estimate of the surface runoff volume and vegetation cover within drainage area. The modelling framework is based on physiographic characteristics of the basin and it can be used for the estimation of sediment yield in other ungauged drainage basins which have similar hydro-meteorological, topographical and land use conditions. The data requirements are much less than most sediment dynamics models and it has the flexibility of model application on multi-temporal and spatial scales. In general the prediction of suspended sediment transport requires the solution of the general diffusion equation and it overall computation of sediment transport (Jimenez and Madsen, 2003). Sediment transport model application is different both in terms of scale and objectives of study, field observations, required accuracy and allocated resources. The accurate result of suspended sediment sampling is the determinations of seasonal mean discharge weighted of suspended sediment as a cross section measurement. The systematic sampling of suspended sediment concentration and the accuracy of value is therefore a concern in the modeling of suspended sediment transport.

Table 3.1 Soil Erosion and Hydrologic Model reviewed

Code	Model	Type	Spatial scale	Application	Reference
ANSWER	Areal Nonpoint Source Watershed Environment Response System	Conceptual	Small catchments	Runoff, Erosion and Sediment	Beasley et.al.,1980
AGPNS	Agricultural Non-Point Source pollution model	Empirical	Small catchments	Runoff and Erosion	Young et al., 1987
SEDD	Sediment Delivery Distributed model	Empirical	Catchment	Erosion	He, Q.,Walling, D.E et., al 2002
CREAMS	Chemical Runoff and Erosion from Agricultural Management Systems	Physically based	Plot and Field	Erosion and Deposition	Knisel ,1980
EUROSEM	European Soil Erosion Model	Physically based	Small catchments	Runoff ,Erosion and Sediment transport	Morgan et al., 1998
LISEM	Limburg Soil Erosion Model	Physically based	Small catchments	Runoff and Sediment	De Roo et al., 1995
WEPP	Water Erosion Prediction Project	Physically based	Hill slope and Catchment	Runoff, Sediment yield, Erosion and soil loss	Lane and Nearing, 1989
SHETRAN	Renamed SHE model	Physically based	Catchment	Runoff, Erosion and Sediment yield	Lucky et al., 2000
EPIC	Erosion Productivity Impact Calculator	Conceptual	Catchment	sediment	Williams et al., 1984,1995
EROSION2D	Erosion-2D	Physically based	Catchment	Runoff and sediment	Schmidt, 1991
GSTAR-1D	Generalized Sediment Transport for Alluvial Rivers-1D	Empirical	Catchment	Sediment transport	Yang et al., 2004
SedNet	The Sediment River Network Model	Conceptual	Hill slope and catchment	Sediment transport	Prosser et al., 2001b
MIKE SHE	MIKE Système Hydrologique Européen (SHE)	Distributed	Catchment	Rainfall-runoff and sediment	Andersen et al.,2001
ROTO	Routing output to Outlet	Distributed	Large River basin	Water and sediment	Arnold eta al.,1995
SWAT	Soil and Water Assessment Tool	Empirical	Catchment and Basin	Runoff, Erosion and Sediment yield	Eckhardt and Ulbrich,2003

USLE	Universal Soil Loss Equation	Physically based	Hill slope	Water, Erosion and sediment	Wischmeier & Smith, 1978
RUSLE	Revised USLE	Physically based	Hill slope	Soil erosion	Kinnell and Risse,1998
UdUSLE	Differentiated USLE	Physically based	Hill slope	Soil erosion	Flacke et al., 1990
KINEROS	Kinematic Erosion Simulation Model	Empirical	Hill slope and catchment	Runoff, Sediment yield and Soil erosion	Woolhiser et al., 1990
EPIC	Erosion Productivity Impact Calculator	Physically based	Hill slope and catchment	Discharge	Williams et al., 1984,1995
TOPMODEL	Topography-based hydrological MODEL	Physically based	Catchment	Soil erosion	Bevan,1997
OPUS	Advanced simulation model for nonpoint source pollution transport	Physically based	Hill slope and catchment	Soil erosion	Ferreira & Smith, 1992
PEPP	Process-oriented erosion prognosis Program	Physically based	Hill slope and catchment	Soil erosion	Schramm, 1994:
LISEM	The Large Scale Catchment Model	Empirical	Hill slope and catchment	Soil erosion	De Roo et al ., 1995
EMSS	Erosion Management System	Conceptual	Catchment	Runoff and Sediment Load	Knisel ,1980
LASCAM	The Large Scale Catchment Model	Empirical	Catchment and Basin	Runoff and Sediment	Viney and Sivapalan, 1999
AGWA	Automated Geospatial Watershed Assessment Tool	Empirical / Physically based	Catchment and Basin	Runoff, Erosion and Sediment yield	Levick et al., 2004
GUEST	Griffith University Erosion System Template	Physically based	Plot and Field	Runoff and Sediment concentration	Boardman.J 1998
TOPOG	Topographic Outcome Predicted by streams erosion model	Physically based	Hillslope	Erosion hazard	Foster and Meyer, 1972
USPED	Universal Soil Loss Equation for Predicating of Soil Erosion	Empirical	Catchment	Erosion and Deposition	Mitasova et al.,1996
Thornes	Regional Scale Erosion Model of Thornes	Empirical /Physically	Hill slope and Catchment	Runoff and Erosion	Thorne et al.,1990

		based			
SEAGIS	Soil Erosion Assessment using GIS	Physically based	Catchment	Erosion and Sediment yield	Danish Hydraulic Institute: 1999
PESERA	Pan–European Soil Erosion Risk Assessment	Empirical	Hill slope	Runoff, Erosion and Sediment	Tsara et al.,2005
SPL	Stream Power Law model	Empirical	Catchment and River basin	Fluvial erosion and River basin	Stock and Montgomery,1999
HSPF	HSPF watershed model	Empirical	Catchment	Runoff and Sediment yield	Bicknell et al., 1993
IQQM	Integrated quantity quality model	Empirical	Catchment	Runoff and Sediment	Rahman J. ,2009/3

* These models can be used for many objectives .We only emphasize the regional scale and if they are able to the model is water discharge and sediment or both.

3.4 Monitoring discharge and suspended sediment flux in the river

Several researchers have investigated acoustic instruments performance to estimate suspended sediment concentration (SSC) and suspended sediment flux. Kostaschuk et al. (2004) investigated the acoustic instrument capacities including velocity, discharge and sediment concentration measurements. They used ADCP as the acoustic instrument for deep water conditions. Accurate velocity and discharge measurements of large rivers have been a problem for many years. These measurements were difficult, time consuming, and sometimes dangerous. To eliminate the problems mentioned above, a new measurement technique and equipment was necessary. This technique was first used to make discharge measurements from a moving boat on the Lower Mississippi River in 1982. The ADCP measured discharges differed less than 5 percent from the simultaneous conventional discharge measurements, which was encouraging for discharge studies. Over the past two decades, ADCP have greatly expanded the ability to make detailed flow measurements in challenging field applications. ADCP have been used since the late 1980s to measure discharge in rivers (Gordon, 1989; Simpson, 1986; Simpson et al., 1990; Morlock, 1996; U.S. Geological Survey, 2001). Comprehensive studies of this technique have shown that the use of ADCP from moving vessels produces reliable discharge measurements under most circumstances tested. However, certain combinations of high velocity and high sediment load can create an underestimation of water discharge. The amount of water stored and moving through the Irrawaddy Basin is unknown but very important in understanding river ecology, sediment delivery and nutrient transport. A review of the literature suggests that ADCP discharge measurement has been used for large river (for example, Mississippi, Amazon and Yangtze). ADCP has also become a more widely used means of estimating suspended solids. The ADCP potential for suspended sediment flux measurements in rivers was soon recognized (Reichel and Nachtnebel, 1994), but very few comparisons with classical sampling estimates have been reported (Filizola and Guyot, 2004).

A velocity profiler was used to measure the velocity profile within the few percents of the water height located near the interface between water and settled sediment. In addition, sediment concentration profiles were measured by a turbidity sensor moved over the water height or by turbidity sensors mounted on a vertical stick, which allows one to record instantaneously the turbidity profile close to the interface between water and settled sediment. *In situ* measurements are compared to theoretical models commonly used. Computation of suspended sediment discharge from interpolated ADCP data depends on the calibration techniques (Holdaway et al., 1999, Krishnappan 2000 and Gartner, 2002, 2004), and the experimental resolution of discrepancies between ADCP data and expected flow properties. To obtain accurate estimations of suspended sediment concentrations (SSC) from ADCP the instrument must be calibrated to the conditions at the time of the survey. By plotting the distribution of measured SSC from water samples against discharge and calibration equation was obtained that allowed for such a specified calibration.

The lack of *in-situ* data limits validation, which makes the estimation of sediment variables in large region, especially difficult. The prediction of realistic sediment budgets requires long term discharge and sediment concentration data (Walling and Webb, 1985; Ludwig and Probst, 1998; Delmas et al., 2009) which often suffer poor availability and reliability (Meybeck et al., 1995, 2003; Walling and Fang, 2003). In particular, uncertainties on both the sampling and calculation methods affect suspended sediment concentration data (Becvar Martin., 2006, Rode and Surh, 2007). Monitoring uncertainties possibly ensue from incorrectly-gauged instruments or lack of precision in laboratory analyses. Moreover, significant drifts in the measured quantities may arise from the location of the sampling in the river section, as suspended sediment concentration varies within cross-sections of the rivers, pleading for series of depth and width-integrated measurements (Horowitz, 1997, Dedkov et al., 2006). The focus of many sediment studies is to develop rating equations that link discharge to sediment (Ketcheson, 1986). The acceptable predictive equations can be developed the continuous river flow records could be used to estimate sediment transport. Sediment availability is subject to seasonal influences and watershed conditions (Ketcheson, 1986 and Williams et al, 1988). Suspended sediments have been identified as a surrogate for other pollutants in storm water (US EPA 2005) as a measure of the overall quality of storm water runoff. Suspended sediments have been selected as a surrogate for trace level pollutants to determine the overall quality of storm water runoff (US Environmental Protection Agency 1993; James, 2003; Technology Acceptance Reciprocity Partnership 2003). The EPA and many states have established limits on the suspended sediment concentration levels which can be discharged into receiving waters and have published guidelines on how to monitor for suspended sediments (US EPA 1992; US EPA 1993; Technology Acceptance

Reciprocity Partnership 2003). To establish the necessary protocol for a monitoring program for suspended sediments, the measurable characteristics of interest should be selected to determine which field and laboratory tests are required (US EPA 1992). This will help shape the overall monitoring methodology such as type of sample, number of samples and analytical method for each sample.

To summarize, prediction of sediment budgets requires long-term discharge concentration data. The suspended sediment flux in a river is important because of its impact on water quality degradation, and environmental problems and thus has been widely studied in many disciplines. Sediment rating curve methods is one of the commonly used and monitoring suspended sediment flux and concentration. A variety of methods and model have been adopted in suspended sediment monitoring, estimation and modelling for understanding sediment transport processes and determining the suspended sediment load.

4. HYDROCLIMATIC CONDITIONS IN THE BASIN

4.1 Introduction

The climate of Myanmar is characterized by strong monsoon influences. Over most parts of Myanmar, there are three defined seasons, the Rainy season (Mid-May to October), the Cold season (November to January) and the Hot season (February to Mid-May). The dry season occurs during the northeast monsoon with average temperatures of between 30°C and 35°C and the wet season during the Southwest monsoon with average temperature between 25°C and 30°C and the cold season with average temperatures of between 20°C and 24°C.

Rainfall is one of the most important climate variables for which historical data are available. Several hydrology studies have used statistical rainfall analysis to demonstrate variations related to geographical location. Such variations are observed with respect to rainfall intensity, daily, monthly, seasonal or annual totals and the occurrence of rainy days. The intensity of rainfall is a measure of the amount of rain that falls over a given time in a specific area and is important for flood forecasting. High intensity rainfall on steep slopes may lead to flash floods or to overbank flooding in plain areas. Forecasting of seasonal rainfall is important for agricultural management and decision making. The analysis presented here deals with the rainfall variation of the Lower Irrawaddy basin during the past twenty one years (1985-2005) and considers possible causes of variation in the context of global climatic changes. The Southwest monsoon wind blows from the Indian Ocean and its intensity causes differences in precipitation received in Myanmar. About three-quarters of the annual rainfall occurs during the southwest monsoon, the upper Irrawaddy basin, which is located inland and sheltered from the direct effect of the Southwest monsoon winds receiving less than 1000 mm of annual rainfall. According to the Department of Meteorology and Hydrology, Myanmar, it generally rains when pre-monsoon cyclones from west approach Myanmar. The coastal region received approximately 5000 mm of rain annually. The deltaic region of lower Irrawaddy basin received annual rainfall is over 2500 mm. During the period 1960-1999, the weather station records of average annual rainfalls were 912 mm in Mandalay, which is located in central Myanmar, 5011 mm in Sittwe, and 4137 mm in Myeik, which is located in coastal Myanmar, 1165 mm in Pyay and 2629 mm in Yangon which is located in Lower Myanmar.

Sometimes cyclones from the east are significant and it eventually rains throughout the Dry Zone from early of May to October. The Southwest monsoon contributes more than 70 % of the annual rainfall in a major portion of Myanmar. The rainfall has to sustain the increasing needs of agriculture and irrigation, the increasing population and the rapid development of urbanization. It is however noted that the Monsoon rainfall over different parts of the country shows considerable inter-annual variability. Heavy rain is usually received in July and August and dry period occurs when dry desiccated winds blow from the south. The climatic condition of the Central basin area is variable from year to year. April is the hottest month and January the coldest month in central part of Myanmar. Generally, the study area receives South West monsoon wind from the end of May but sometimes monsoon arrives one week early or late. August is the month with the heaviest rainfall in the lower Irrawaddy basin and there are some periods without precipitation.

The Southwest monsoon is the main source for Myanmar's seasonal rains, but easterly winds and local depressions across the Gulf of Thailand often bring post monsoon rains, that sometimes penetrate to the central part of Myanmar. However, flooding and drought are frequent phenomena which have a direct impact on the agriculture, health, water and other socio-economic sectors of the region. The statistical analysis of changes in frequency and variability of monsoon rainfall can provide basic information about the influences of hydro-climate change in the lower Irrawaddy basin.

4.2 Methods and Materials

This study examines daily rainfall data of the summer monsoon months (1985 to 2005). The precipitation data of the period 1985-2005 were obtained by from Department of Meteorology and Hydrology, Myanmar (DMH). Meteorological data is essential for water resource planning, hydrological and environmental research. In Myanmar, this data is difficult to obtain and limited for continuous time series data. In this study provides the rainfall datasets from Pyay Meteorology and Hydrology weather station, which is located in the central of the Lower Irrawaddy basin (Figure 4.1). Table 4.1 shows the monthly rainfall of Pyay station (1985-2005). Rainfall statistics of mean calculation, dispersion of standard deviation and distribution (variability coefficient), frequency analysis were calculated for the data. The data series was tested for normality using Excel and SPSS.

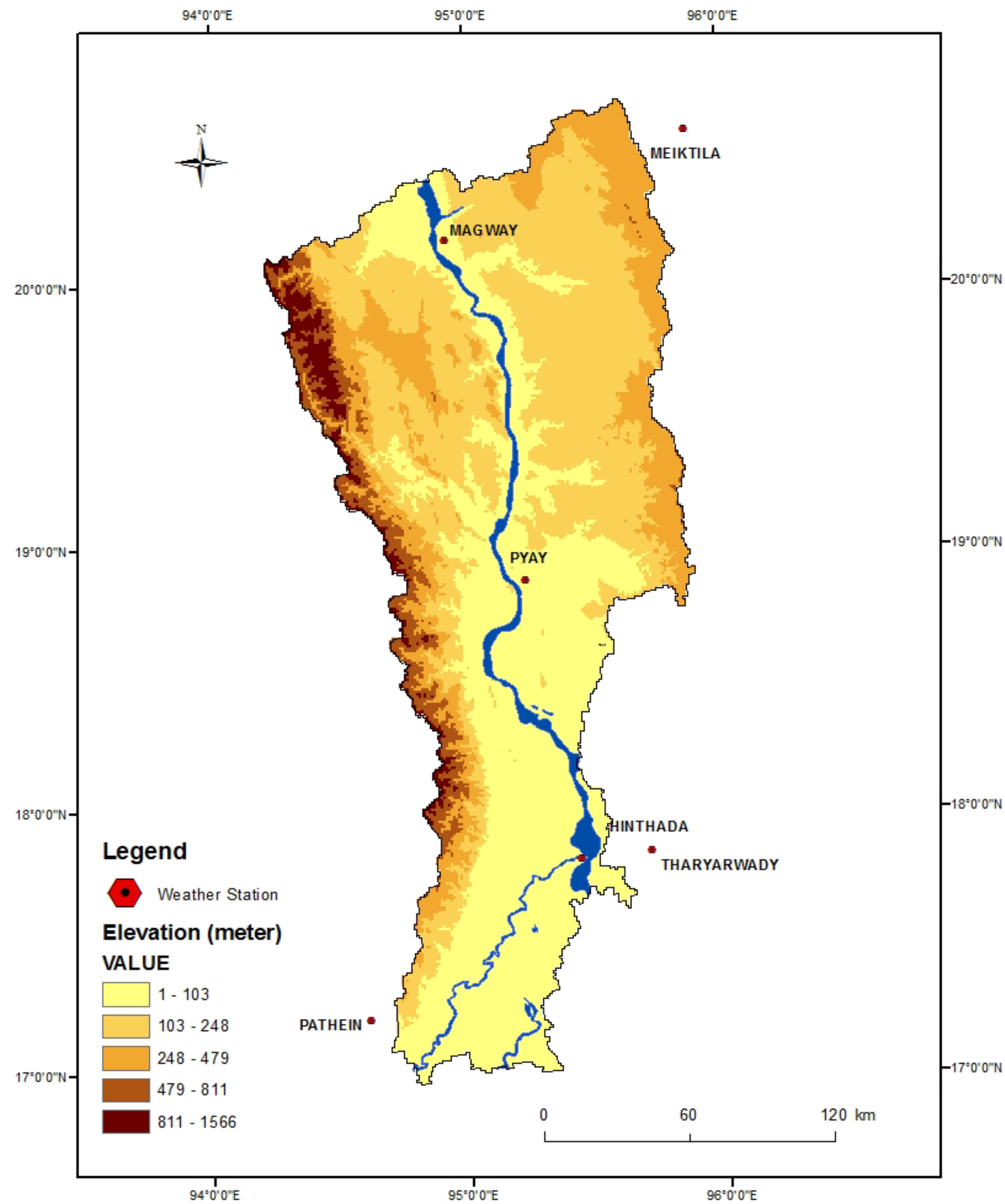


Figure 4.1 Weather Stations in the Lower Irrawaddy basin

Table 4.1 Monthly Rainfalls (mm) at Pyay Station in Lower Irrawaddy basin (1985-2005)

Month	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Jan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0
Feb	0	0	0	0	0	0	0	0	0	0	0	19	0	0	0	0	0	0	0	0	0
Mar	0	0	0	0	0	0	21	0	12	8	0	9	38	0	0	14	0	0	0	0	0
Apr	7	6	5	4	0	0	48	7	16	25	25	43	8	22	30	29	0	0	6	116	35
May	135	59	5	141	146	0	89	221	49	76	150	177	40	155	116	209	164	394	64	198	15
Jun	170	205	194	174	215	160	168	195	162	219	373	250	192	161	193	248	312	326	303	103	370
Jul	172	173	107	302	179	233	120	259	138	252	290	141	163	165	178	143	221	141	89	255	212
Aug	209	251	395	324	300	230	321	306	224	165	162	222	247	103	352	122	147	261	188	224	224
Sep	101	196	209	195	99	159	124	134	211	127	228	349	189	76	236	142	184	320	172	181	423
Oct	91	41	38	169	182	159	113	191	74	78	66	100	48	86	170	132	118	50	116	117	151
Nov	64	87	140	272	0	72	74	61	0	30	77	99	9	27	38	0	69	70	0	0	77
Dec	0	0	0	0	0	0	19	0	0	0	0	0	2	0	0	0	0	0	0	0	56
Total	949	1018	1093	1581	1121	1013	1097	1374	886	980	1371	1409	936	795	1313	1039	1215	1562	954	1194	1563

In Myanmar, the onset of the southwest monsoon has become later and its withdrawal earlier. During the early to peak monsoon period (mid-May to August), extreme rainfalls can occur in the Upper Irrawaddy basin area wide spread flooding and flash floods occur during the monsoon months (June to October). Heavy rainfall is received due to cyclonic storm crossing south west Myanmar during early-monsoon and late-monsoon. Table 4.2 shows the percentage of occurrences of floods in rainy season months at Pyay station. In the Lower Irrawaddy basin along the river and streams are subject to normal floods during monsoon and multiple floods occur when monsoon is intensified at its peak. In the study area of Pyay, there are 14 times of above danger level (2900 cm) and bank full flood occurred in the period of 1966-2005 (APPENDIX A). Table 4.3 shows the over bank full flood occurred in Pyay 2004 at Lower Irrawaddy River.

Table 4.2 Percentage of occurrences of floods along Irrawaddy River, Pyay station

River station	% of Floods occurrences in Months					% change of a flood in any year	Flood Frequency
	Jun	Jul	Aug	Sep	Oct		
Pyay	0	24	37	27	12	30	1 time in 3 years

Table 4.3 River flood in Pyay (2004)

Stations	DL (cm)	Flood Peak (cm)	Flood Peak (cm)	Flood Duration above DL	Record	Above DL (cm)
Pyay	2900	2971	31.7.04	9 Days 15 Hours	Second	+ 71
		2920	20.9.04	3 Days 2 Hours		+ 20

DL=Danger Level

4.3 Analysis of Rainfall in the Lower Irrawaddy basin

Daily rainfall data and rainfall fluctuation

Sequences of daily rainfall are required increasingly, not only for hydrological and climatologically purposes but also to provide inputs for models of crop growth, landfills, tailing dams, land disposal of liquid waste and other environment projects. Although rainfall can be measured over different intervals, the highest temporal resolution of rainfall data made available in Myanmar is at the daily timescale. The daily data form the basis for monthly, annual and decadal of rainfall series. A statistical analysis of daily maximum rainfall data at Pyay station during the monsoon (June-September) for a twenty one year period is presented. El Niño and La Niña events are classified by a number of different criteria. Some classification systems use the strength and sign of the Southern Oscillation Index (SOI) (Figure 4.2), while others use Sea Surface Temperature (SST) anomalies for a variety of Pacific regions. Still others use a combination of several criteria to gauge the type and strength of the event. Table 4.4 shows the list of consensus El Niño & La Niña Years.

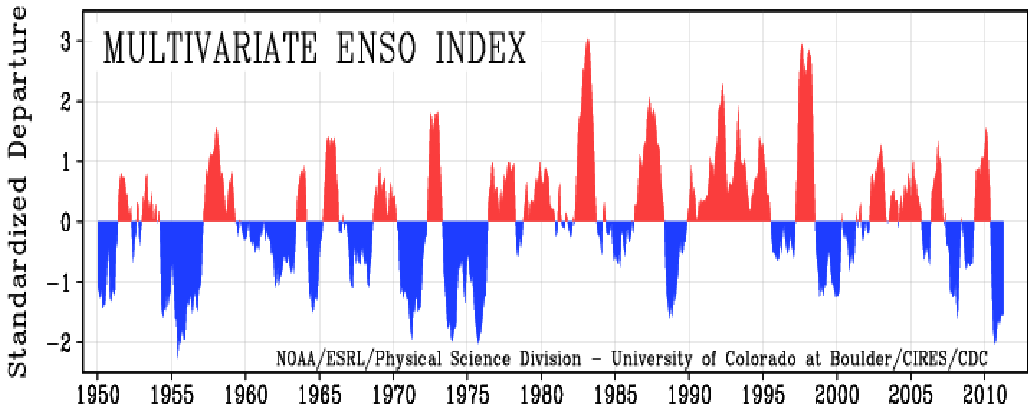


Figure 4.2 Multivariate ENSO index

Source: http://www.esrl.noaa.gov/psd/enso/mei/LaNina

According to the1900-2008 record of Department of Meteorology and Hydrology Myanmar, the years in which the Upper Irrawaddy basin area of the central Dry Zone experienced the most significant drought were: 1954, 1957, 1961, 1972, 1979 and 1991.

The El Niño -Southern Oscillation (ENSO) phenomenon which is known to influence year-to-year fluctuations in monsoon rainfall over Asia influences the variability of Myanmar's rainfall too. Over the past 40 years (1960-1999), all El Niño years resulted in large deficient rainfall in Myanmar. Myanmar the El Niño events have been more frequent than ever during the 1990s in Myanmar. The weather in 1998 and 1999 were obvious with 1998 being an El Niño year and 1999 being a La Niña year. Therefore, it could be suggested that the mean annual temperatures during El Niño years are generally above the normal. The relation of monsoon rainfall to El Niño events clearly reveals that the monsoon rainfalls in Myanmar are below normal in most of the El Niño years (Tun Lwin 2000, Myanmar Agriculture in Brief 2008, Myanmar-NCEA report 2010).

Table 4.4 El Niño & La Niña Years: A Consensus List (1984-2004**)**

Year	Event
1984-85	
1985-86	
1986-87	
1987-88	El Niño
1988-89	Strong La Niña
1989-90	
1990-91	
1991-92	Strong El Niño
1992-93	El Niño
1993-94	El Niño
1994-95	El Niño
1995-96	
1996-97	
1997-98	Strong El Niño
1998-99	La Niña
1999-00	
2000-01	La Niña
2001-02	
2002-03	El Niño
2003-04	

Source: http://www.cdc.noaa.gov/ENSO/enso.mei-index.html

Table 4.5 Mean rainfall per day, maximum daily rainfall and annual rainfall (mm) for each year from 1985 to 2005

Year	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Mean	2.59	2.78	2.99	4.31	3.07	2.77	3	3.75	2.42	2.68	3.75	3.84	2.56	2.17	3.59	2.83	3.32	4.27	2.61	3.26	4.39
Max	71	68	72	124	53	52	56	70	44	39	121	82	40	83	69	61	53	112	72	60	79
Total	949	1018	1093	1581	1123	1013	1097	1347	886	980	1371	1409	936	795	1313	1039	1215	1562	954	1194	1605

Mean= Mean rainfall per day (mm)
Max = Maximum daily rainfall (mm)

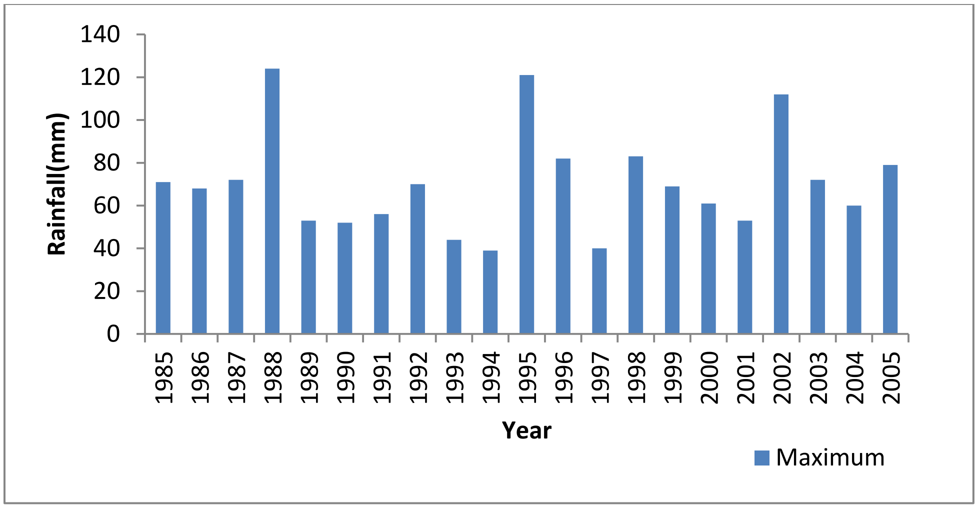


Figure 4.3 Maximum Daily Rainfall (mm) for each year from 1985-2005

Table 4.5 shows the annual rainfall statistics of Pyay station for the period of 1985-2005. The mean and maximum rainfall data have been calculated for each year. The maximum daily rainfall has been plotted to indicate the degree of year to year fluctuation (Figure 4.3). Maximum daily rainfall exceeded 120 mm in 1995, 1998 and 2005 but in other years the wettest day in the year is less than 80 mm. Figure 4.4 plots the monthly rainfall for the period of 1985 to 2005 which demonstrates the seasonal peak of rainfall in July, August and September.

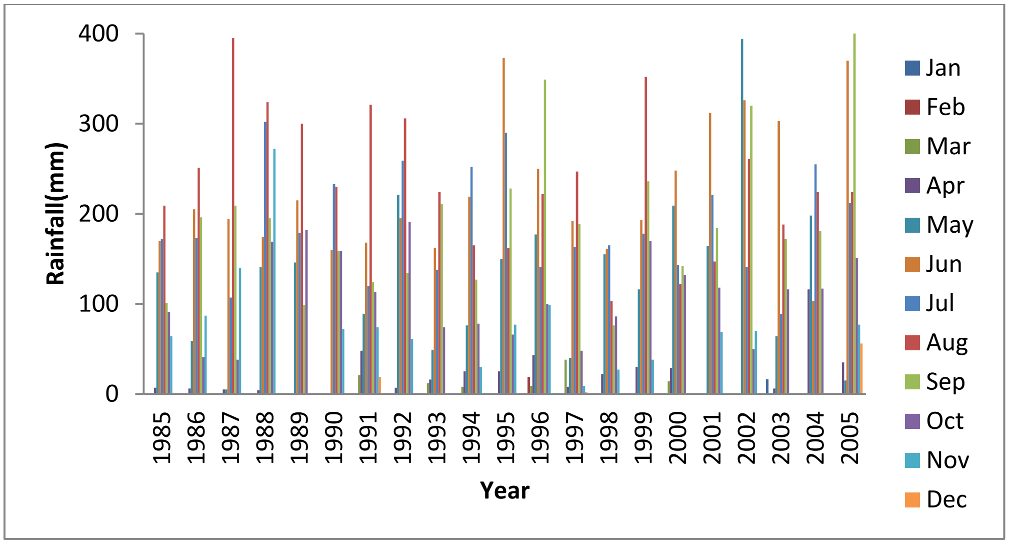


Figure 4.4 Monthly Rainfall for the period of 1985-2005

In the Lower Irrawaddy basin the rainy season can further be divided into pre-monsoon season (Mid-April to June), monsoon season (July to Mid-September) and the post-monsoon season (Mid-September to Mid-November). The time duration of each part of the rainy season depend on the basis of positive deviation from the mean condition. Figure 4.5 illustrates the rainy days of the year 1985-2005 at Pyay Station. Each year received less than 125 rainy days in the study period. Table 4.6 shows the timing of rainy season wet and dry days in Pyay from 1985 to 2005. Each year the start and end days of the wet seasons were identified. The Lower Irrawaddy basin area receives both summer and winter rains, but the contribution of Indian summer monsoon rains is higher in some years. For example, 1995 received the highest monsoon rainfall. However, summer monsoon is shorter and early withdraws duration after 1985.

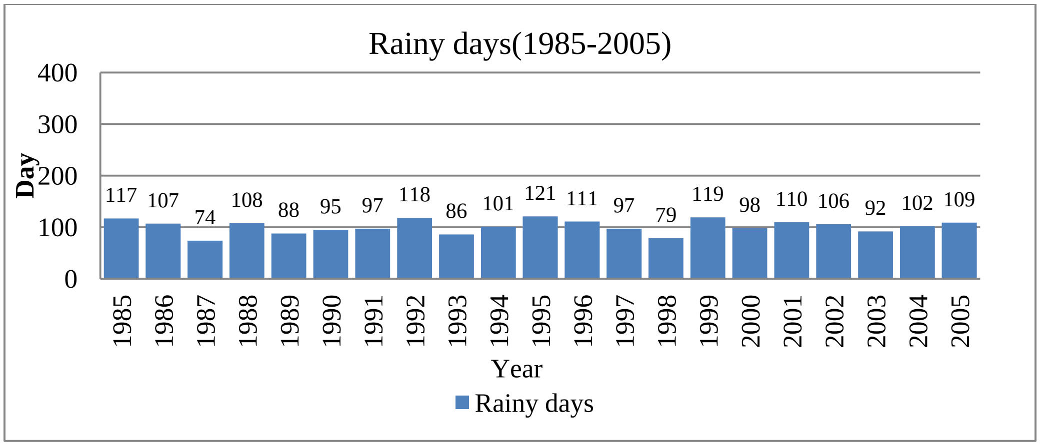


Figure 4.5 Rainy days of the year 1985-2005 at Pyay Station

Table 4.6 Timing of the rainy season (start and end dates) and number of wet and dry days in Pyay (1985-2005)

Year	Rain Start	Rain End	Wet days	Dry days
1985	17-Apr	21-Nov	117	248
1986	25-Apr	30-Nov	107	258
1987	28-Apr	16-Nov	74	291
1988	15-Apr	21-Nov	108	258
1989	12-May	16-Oct	88	277
1990	4-Jun	11-Nov	95	270
1991	21-Mar	21-Nov	97	268
1992	30-Apr	23-Nov	118	248
1993	26-Mar	31-Oct	86	279
1994	26-Mar	27-Nov	101	264
1995	5-Apr	26-Nov	121	244
1996	5-Feb	7-Nov	111	255
1997	23-Mar	15-Dec	97	268
1998	17-Apr	23-Nov	79	286
1999	15-Apr	3-Nov	119	246
2000	29-Mar	29-Oct	98	267
2001	17-Jan	16-Nov	110	255
2002	14-Apr	30-Nov	106	259
2003	30-Apr	16-Oct	92	273
2004	3-Apr	20-Oct	102	263
2005	7-Mar	26-Dec	109	256

4.4 Analysis of rainfall frequency

Frequency analysis of precipitation data requires a relatively long record from a single gauge at a particular site. It can be used to calculate the frequency of other hydrologic events. In Lower Irrawaddy Basin of Pyay area is a commonly associated with less rain and sometime flood event particularly in recent decades since the 1970s. There are two possible procedures for computing the frequency distribution of daily rainfalls at a station of which are ranking and plotting all individual rainfall data and ranking and plotting grouped analysis. Table 4.7 shows the frequency distribution of daily rainfall using data from the official Pyay weather station from 1985 to 2005. The average frequency of daily rainfall with less than 25 mm is 343 times per year and the daily rainfall over 100 mm occurred 6 times over the 1985-2005 period. However the highest daily rainfall of 121 mm occurred in August 2002.

The frequency analysis of class interval for rainfall is less than 25 mm, 25 to 50mm, 50 to 75 mm, 75 to 100 mm and over 100 mm. The summary result shows no rain days is 2163, rainfall less than 25 mm is 1901 days and rainfall above 25 mm is 326 days in study the year of 1989 to 2005. However, it is expected that total rainfall amount for a given duration is obtained from daily rainfall recorded data set. At the Lower Irrawaddy basin area, the daily rainfall data are available for very limited number of gauges and for a very short period of record of twenty one years (1985-2005).

Table 4.7 Frequency analysis of Daily Rainfall at Pyay Station in Lower Irrawaddy basin (1985-2005)

Rainfall(mm)	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Mean
0 to 0.1	254	271	269	259	263	257	266	248	278	258	252	256	268	285	247	270	258	260	270	262	257	5508
0.1 to 5	61	34	46	42	43	48	49	45	37	46	50	45	40	39	50	44	43	42	36	47	38	925
5 to 10	22	27	20	22	21	25	13	27	25	28	20	21	24	15	28	23	25	30	33	22	20	491
10 to 15	10	10	7	7	17	15	7	15	7	16	12	14	9	9	13	9	12	5	10	12	13	229
15 to 20	9	14	7	11	6	6	10	10	4	5	7	6	13	6	9	3	6	5	5	3	9	154
20 to 25	3	1	4	6	2	3	6	10	2	7	10	9	5	4	2	5	7	6	1	3	6	102
25 to 30	0	0	1	4	3	8	6	2	4	1	6	4	0	2	6	3	5	2	5	7	8	77
30 to 35	4	4	4	7	2	1	4	3	4	2	1	4	4	3	4	3	4	2	1	2	5	68
35 to 40	2	1	0	4	2	1	1	1	2	2	1	2	2	1	2	1	4	3	1	3	1	37
40 to 45	0	0	3	0	3	0	1	1	2	0	3	0	0	0	1	3	0	1	0	2	3	23
45 to 50	0	2	1	1	2	0	1	0	0	0	1	2	0	0	0	0	0	2	2	1	2	17
50 to 55	0	0	1	0	1	1	0	2	0	0	0	0	0	0	1	0	1	1	0	1	0	9
55 to 60	0	0	1	0	0	0	1	1	0	0	1	1	0	0	1	1	0	0	0	1	0	8
60 to 65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	2
65 to 70	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	3
70 to 75	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	1	0	2	8
75 to 80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	2
80 to 85	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	2
85 to 90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90 to 95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
95 to 100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100 to 105	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
105 to 110	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
110 to 115	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
115 to 120	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
120 to 125	0	0	0	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3
No of Rain Days	112	94	96	107	102	108	99	118	87	107	113	110	97	80	118	96	107	105	95	104	108	2163
Rainfall <25 mm	359	357	353	357	352	354	351	355	353	360	351	351	359	358	349	354	351	348	355	349	343	1901
Rainfall >25 mm	7	8	12	19	13	11	14	11	12	5	14	15	6	7	16	12	14	17	10	17	22	262
Rainfall >50 mm	1	1	1	3	1	1	1	4	0	0	2	3	0	1	3	2	1	7	1	2	3	40
Rainfall >75 mm	1	0	0	3	0	0	0	0	0	0	1	2	0	1	0	0	0	5	1	0	3	18
Rainfall >100mm	0	0	0	3	0	0	0	0	0	0	1	0	0	0	0	0	0	2	0	0	0	6

Discussion

In this study, the daily maximum rainfall received during monsoon months of May to October with other months are characterized by drought. The variability of rainfall for the Lower Irrawaddy basin (1985 to 2005) shows that the highest mean rainfall is 4.39 mm and the lowest mean rainfall 2.17 mm per day. During the study period, the lower Irrawaddy basin experienced the maximum daily rainfall is 80-125 mm per year. Particularly, western part of this study area is rain-shadow and northern part is dry zone of central Myanmar. Deforestation is another human impact, and most of the natural vegetation of the study area has been used for farming and without replanting of new trees. The mountains slopes and barren area exposed to soil erosion of the study area.

The study of rainfall over lower Myanmar received the summer monsoon season is normal in 1985 to 2005. This has naturally led to a lot of concern and the southwest monsoon about the causes. It can be see clearly that the shortfall in rainfall is a part of the natural variability. This variation of rainfall generally triggers to change in air pressure, wind speed and direction, increase in temperature, carbons, exhaust gases from industries, and deforestation on global scale. Analysis of the daily rainfall data showed that there is less than that annual mean rainfall and more below the long term average value. Generally, forecasts for seasonal rainfall are generated, whether other climate factors of event could have been foreseen, and the perspective on the problems and prospects of forecasting the summer monsoon rainfall over the Lower Irrawaddy basin.

4.5 Overview of previous reported water discharge and sediment flux

This study relies on 19th century historical data of water discharge and suspended sediment and the record of 1960s data of Department of Meteorology and Hydrology of Myanmar. Figure 4.8 shows the danger level of Irrawaddy River at Pyay station. The Irrawaddy River discharge and sediment study is very rare and limited available dataset. The earliest record of Irrawaddy River sediment data was an engineering report. Robert Gordon, a civil engineer in charge of river works in Burma during the late 19th Century, investigated the magnitude and duration of flood events on the Irrawaddy for the Government of India. Gordon selected the Seiktha (50 km downstream of Pyay) as the main measurement site for velocity and sediment concentration. He also recorded eight years monthly discharge data from 1869-1879, but where the width of the river made multiple cross-sectional measurements of sediment load. Gordon (1885) presented monthly discharge data collected between 1869 and 1879, and one year of sediment load data (1877-1878), to the Royal Geographical Society without details of his field methods or sampling locations (Table 4.8 and Table 4.9). Gordon's original report, containing his full daily discharge, rainfall and sediment load dataset, survey maps, channel cross-sections and a detailed description of sampling technique (Gordon 1879), was found in the archives of the Royal Geographical Society (RGS) in 2005. In an original 19th Century dataset by Gordon (1885) suspended sediment load record was calculated to be 261MT/year.

The current study reanalyzed the 19th Century Irrawaddy data and subsequent early 20th Century engineering reports. The data are of remarkable quality, particularly since there are a full range of flows, including monsoon peak discharge, and sediment loads were measured at three water depths, including the lower part of the water column. In 2005 and 2006, field data were collected the results were compared with the original 19th Century data. Robinson et al. (2007) have re-analyzed the original data and concluded that the 10-yr average of water flux for the Irrawaddy River at Seiktha was 41153 km^{3}yr, transporting 266-334 MT of suspended load. More than 90% of the annual sediment load was delivered during the monsoon between mid-June and mid-November. The original 19th century data underestimated the actual sediment load and Robinson et al. (2007) suggest the sediment load is (364 ± 60 x 10^6 t/year). In compilations of global river statistics, the Irrawaddy River currently ranks fifth in the world in terms of sediment suspended load (265 MT/yr; Milliman and Meade, 1983). A more recent study of discharge and suspended sediment load by Furuichi et al. (2009) yielded a load as 325 ± 57x10^6 t/year. Other estimates of the sediment load dataset delivered to Irrawaddy River form Pyay gauging Station measurement are mainly based on monitoring water level and suspended sediment concentration. Table 4.10, Table 4.11 and Table 4.12 show the annual discharge and annual suspended sediment load data for 1966-1996 at the Pyay gauging station.

Table 4.8 Irrawaddy River danger level (DL) at Pyay station

Station	Year	Danger Level(cm)	Max .Water level(cm)	Flood durations(day)	Above DL(mm)
Pyay	8/15/1974	2900	3025	13	125
Pyay	9/22/2007	2900	2918	2	18

4.6 Annual water discharge and sedimentation

Annual water discharge data provided by the 19th Century Irrawaddy record of 1870-1879 are presented in Figure 4.6. The Irrawaddy water flow data have been recorded at Pyay Station since 1966 by the Department of Meteorology and Hydrology of Myanmar. Furuichiet al. (2009) determined the monthly discharge from 1966 to 1996. The discharge is highest in the rainy season of July to October and represents 71% of the mean annual discharge wire 58% in August. Figure 4.7 shows the mean total suspended sediment concentration and annual discharge at Pyay station of the Lower Irrawaddy basin.

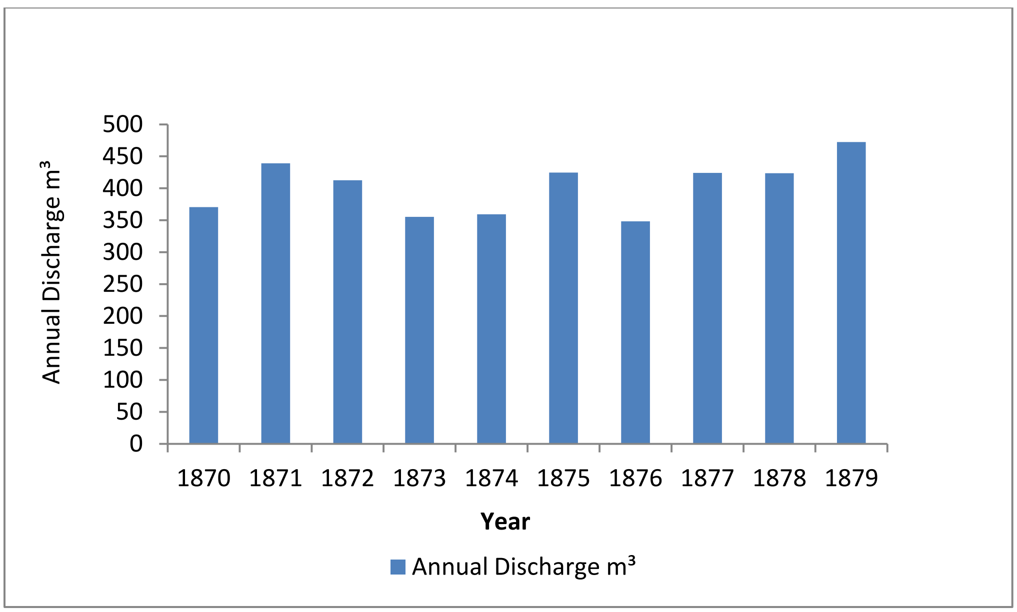


Figure 4.6 Annual discharge at Seiktha (1870 to 1879)

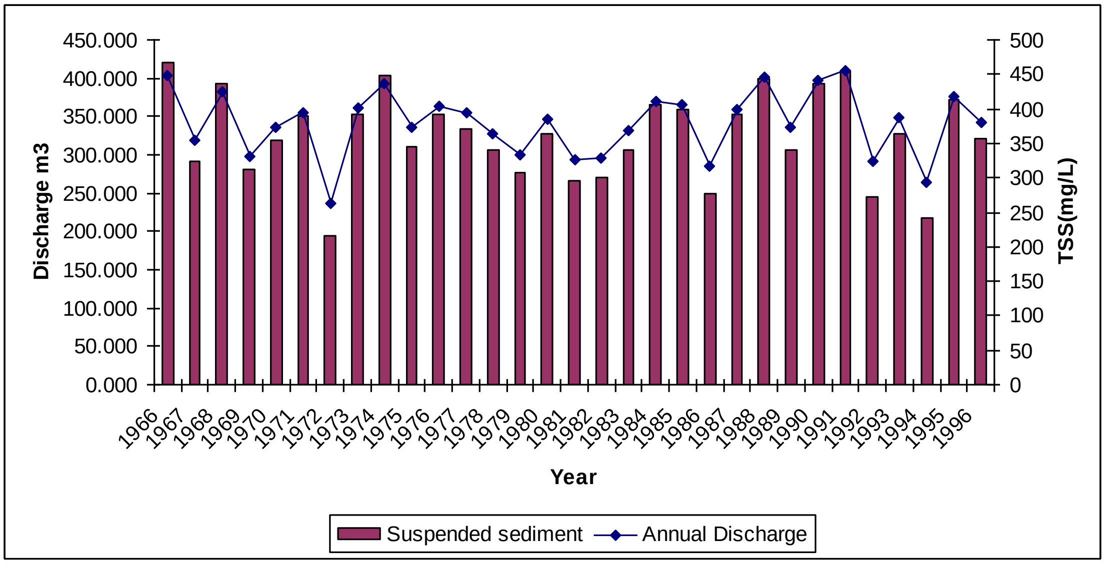


Figure 4.7 Annual suspended sediment and discharge at Pyay Station (1966 to 1996)

Table 4.9 Monthly and Annual discharge of Seiktha (1869-1879)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual discharge
1869						31.21	68.42	74.82	64.744	60.829	13.09		
1870		5.361	4.723	5.704	7.49	21.51	74.742	84.3	78.635	48.317	17.93	12.83	361.54
1871	7.93	5.248	6.675	9.34	11.624	40.08	80.082	91.96	85.01	52.532	33.03	15.59	439.109
1872	9.38	6.799	6.213	6.518	14.015	18.93	76.979	85.11	69.985	73.728	29.63	15.21	412.487
1873	9.64	6.664	6.466	6.595	8.644	33.45	68.238	76.59	56.714	47.039	24.29	10.81	355.143
1874	6.71	4.812	6.504	10.67	18.236	21.43	65.902	63.48	67.702	58.037	24	11.79	359.262
1875	7.82	5.538	6.088	10.98	21.615	40.57	84.628	98.56	75.417	44.937	17.76	10.58	424.495
1876	6.66	4.666	6.171	9.005	10.556	25.1	80.076	88.88	47.83	41.439	17.58	10.28	348.248
1877	5.98	4.465	4.167	8.056	7.14	28.4	60.196	110.3	77.867	75.882	27.27	14.19	423.96
1878	9.35	6.312	8.73	10.67	10.847	16.02	72.994	87.33	83.901	74.012	28.56	14.87	423.599
1879	9.43	6.718	7.274	6.597	9.461	56.05	96.673	99.6	90.597	50.152	26.9	13.01	472.466
Total	72.9	56.583	63.01	84.15	119.63	332.8	828.93	961	798.4	626.9	260	129.2	4020.309
Mean	8.1	5.6583	6.301	8.415	11.963	30.25	75.357	87.36	72.582	56.991	23.64	12.92	402.0309

Unit: Discharge (10^9 m^3)

Source: Gordon (1885), Robinson et al. (2007)

Table 4.10 Monthly Mean Suspended load of Seiktha (1877-1878)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual TSS
Mean	2.4	1.1	1.3	3.2	7.1	21.6	51.5	69.7	50.3	35.5	11.3	6.3	261.3

Unit: Sediment load (10^6 t)

Source: Gordon (1885), Robinson et al. (2007)

Table 4.11 Annual discharge of the Irrawaddy at Pyay (1966-1996)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual discharge
1966	10.20	7.04	6.91	7.22	8.43	40.93	83.11	90.66	95.01	66.40	19.67	12.92	448.49
1967	9.35	6.81	7.45	7.43	10.67	19.26	63.44	70.43	51.51	71.09	24.90	13.14	355.48
1968	8.95	5.55	5.74	7.88	9.60	34.98	98.99	82.79	83.53	54.67	21.61	9.95	424.24
1969	7.15	5.36	5.37	5.10	6.30	27.79	71.59	82.81	65.88	32.07	12.63	8.37	330.42
1970	6.16	4.63	4.98	7.42	12.48	25.28	63.60	96.24	52.29	52.44	34.42	12.45	372.37
1971	7.14	5.04	4.40	4.76	7.40	35.02	67.24	88.74	74.52	61.18	26.52	13.49	395.44
1972	8.45	6.32	5.60	6.83	10.32	17.05	49.72	68.76	46.44	25.50	10.75	8.13	263.86
1973	5.30	4.12	5.03	4.88	10.58	37.82	70.04	95.59	63.12	44.24	41.42	18.49	400.63
1974	8.99	5.99	6.10	7.86	14.81	28.14	84.82	103.79	81.37	56.43	22.46	15.18	435.95
1975	8.99	6.74	6.82	7.95	10.48	29.95	64.86	74.76	64.80	55.49	29.13	13.32	373.26
1976	9.41	6.64	7.70	10.17	11.64	42.32	97.21	80.21	59.73	44.64	18.48	15.80	403.95
1977	9.07	6.82	9.35	11.96	16.15	30.58	67.29	76.09	85.19	45.14	23.00	12.89	393.51
1978	9.24	6.45	6.42	6.61	12.89	34.84	82.44	74.98	56.74	46.56	15.64	10.71	363.53
1979	7.75	5.70	5.42	7.04	7.63	11.21	47.72	62.02	79.12	66.66	18.18	13.79	332.23
1980	8.49	6.10	7.43	8.67	13.29	31.85	59.65	83.11	58.45	73.29	23.97	10.59	384.88
1981	7.38	5.81	7.02	8.24	8.47	29.07	70.37	69.74	68.23	28.70	14.43	9.14	326.60
1982	6.40	4.78	5.22	6.81	8.56	28.54	63.97	76.65	59.67	44.71	14.63	8.96	328.89
1983	7.00	5.48	7.61	13.17	14.75	20.68	47.88	75.23	74.73	59.46	30.54	12.76	369.27
1984	9.69	6.51	5.88	7.12	11.44	42.38	82.45	84.49	77.16	50.45	23.06	11.06	411.69
1985	8.36	6.36	7.30	9.28	10.21	56.66	83.68	79.42	69.98	46.41	17.44	10.56	405.66
1986	8.10	6.29	6.56	8.52	9.52	11.06	47.48	59.58	66.89	59.58	21.03	11.47	316.06
1987	8.65	6.76	6.93	9.34	9.54	30.47	60.22	94.77	76.69	63.65	19.69	12.93	399.64
1988	9.63	7.31	10.02	10.04	15.66	39.38	68.43	85.56	96.54	57.95	29.12	15.30	444.92
1989	9.73	7.70	7.84	8.64	12.75	21.63	57.13	75.97	54.60	70.48	32.19	13.73	372.38
1990	9.71	7.97	8.89	12.13	19.33	48.58	98.52	79.67	58.51	63.56	22.13	12.90	441.92
1991	9.99	7.66	8.04	10.00	21.43	37.38	91.03	95.64	59.32	64.34	34.88	14.58	454.28
1992	10.91	8.29	9.44	14.12	12.22	14.08	62.24	56.03	43.70	53.62	26.76	12.48	323.88
1993	9.22	7.17	9.10	9.02	14.17	35.44	63.98	72.99	80.85	50.15	23.92	12.10	388.11
1994	8.47	6.56	7.22	10.86	9.60	22.72	52.20	59.43	52.34	40.71	14.35	9.77	294.23
1995	7.15	5.34	5.91	5.72	17.84	35.76	94.83	77.18	59.15	67.19	26.27	16.42	418.74
1996	9.35	6.46	9.31	12.89	19.59	21.98	77.22	83.58	63.41	47.24	17.83	11.35	380.20
Total	264.37	195.79	217.00	267.68	377.70	942.83	2193.34	2456.89	2079.45	1663.99	711.03	384.68	11754.74
Mean	8.53	6.32	7.00	8.63	12.18	30.41	70.75	79.25	67.08	53.68	22.94	12.41	379.19

Unit: Discharge (10^9 m^3)

Source: Department of Meteorology and Hydrology, Myanmar

Table 4.12 Annual Suspended Sediment load the Irrawaddy at Pyay (1966-1996)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total
1966	4.37	2.69	2.51	2.71	3.33	32.14	87.07	98.56	106.85	63.21	11.30	6.12	420.84
1967	3.86	2.56	2.79	2.82	4.66	10.97	59.23	68.76	44.63	69.68	15.82	6.27	292.03
1968	3.62	1.92	1.93	3.07	4.01	25.69	111.73	86.58	88.92	47.90	12.93	4.21	392.50
1969	2.63	1.82	1.75	1.65	2.20	18.50	70.37	86.62	63.38	22.38	6.01	3.30	280.61
1970	2.13	1.48	1.57	2.81	5.82	16.16	59.44	107.31	45.59	45.13	25.10	5.80	318.36
1971	2.63	1.67	1.32	1.50	2.76	25.74	64.35	95.59	75.56	56.24	17.31	6.51	351.16
1972	3.34	2.30	1.86	2.50	4.44	9.22	41.84	66.44	38.49	16.14	4.77	3.16	194.49
1973	1.72	1.25	1.59	1.55	4.60	28.72	68.21	106.29	59.63	35.42	32.70	10.20	351.88
1974	3.65	2.14	2.10	3.05	7.43	18.84	89.63	119.53	85.67	50.12	13.66	7.70	403.52
1975	3.65	2.53	2.46	3.10	4.54	20.59	61.12	74.86	61.90	48.93	19.79	6.39	309.84
1976	3.90	2.47	2.93	4.41	5.27	33.71	108.87	82.76	55.11	35.88	10.34	8.15	353.80
1977	3.70	2.57	3.86	5.56	8.41	21.21	64.42	76.76	91.45	36.46	14.13	6.10	334.60
1978	3.79	2.38	2.26	2.39	6.10	25.55	86.07	75.18	51.23	38.09	8.15	4.68	305.85
1979	2.95	1.99	1.77	2.61	2.89	5.07	39.46	57.34	82.31	63.56	10.10	6.71	276.75
1980	3.36	2.19	2.78	3.51	6.37	22.48	54.25	87.05	53.43	72.76	14.98	4.61	327.78
1981	2.75	2.04	2.56	3.27	3.35	19.74	68.67	67.79	66.63	19.11	7.27	3.73	266.91
1982	2.25	1.55	1.68	2.49	3.40	19.22	59.94	77.58	55.03	35.96	7.41	3.63	270.12
1983	2.55	1.88	2.88	6.38	7.39	12.14	39.64	75.52	75.86	54.00	21.17	6.01	305.42
1984	4.06	2.41	1.99	2.65	5.14	33.78	86.08	89.13	79.41	42.71	14.18	4.91	366.46
1985	3.29	2.33	2.71	3.87	4.38	51.11	87.91	81.60	69.09	37.92	9.52	4.59	358.31
1986	3.14	2.29	2.33	3.43	3.96	4.97	39.17	54.15	64.77	54.15	12.43	5.16	249.95
1987	3.45	2.54	2.52	3.91	3.97	21.10	54.98	104.99	78.72	59.50	11.32	6.12	353.13
1988	4.02	2.84	4.26	4.33	8.05	30.42	65.98	90.75	109.31	52.05	19.78	7.79	399.57
1989	4.08	3.06	3.00	3.50	6.00	12.95	51.00	76.59	48.49	68.82	22.82	6.68	306.98
1990	4.07	3.21	3.59	5.67	10.87	41.05	110.97	81.97	53.52	59.39	13.37	6.11	393.80
1991	4.24	3.03	3.11	4.31	12.59	28.25	99.13	106.37	54.57	60.43	25.59	7.27	408.89
1992	4.81	3.40	3.91	7.05	5.65	7.02	57.63	49.61	35.29	46.59	17.53	5.83	244.31
1993	3.78	2.76	3.71	3.72	6.98	26.18	59.95	72.34	84.88	42.36	14.94	5.57	327.17
1994	3.35	2.43	2.67	4.84	4.01	13.88	44.84	53.96	45.65	31.46	7.21	4.11	218.41
1995	2.63	1.81	2.01	1.94	9.69	26.51	105.08	78.34	54.35	64.28	17.08	8.62	372.33
1996	3.86	2.38	3.83	6.18	11.08	13.24	78.40	87.76	60.03	38.89	9.83	5.08	320.56
Total	105.63	71.90	80.21	110.76	179.34	676.13	2175.41	2538.07	2039.74	1469.52	448.52	181.11	10076.32
Mean	3.41	2.32	2.59	3.57	5.79	21.81	70.17	81.87	65.80	47.40	14.47	5.84	325.04

Unit: Sediment load (10^6 t)

Source: Department of Meteorology and Hydrology, Myanmar

5. LAND USE/COVER CHANGE IN THE LOWER IRRAWADDY BASIN

5.1 Land use/cover change in the basin

The context of increasing population densities and pressure to expand agricultural land in the Lower Irrawaddy basin has been discussed in Section 2.4. In order to understand the forces of change, it will be necessary to conduct studies illustrate the nature of land use and land cover change over time. Integrated application of Geographic Information System (GIS) and Remote Sensing (RS) has come to be recognized as an important approach to natural resource management. Moreover, these two technologies are also important for decision-supporting tools. As this approach seeks to investigate, one of sub-basins representing Lower Irrawaddy basin for understanding the linkages of land use/cover change during the period from 1989 to 2010. Therefore, this study aims to determine the land use and land cover condition as it may explain the change of water and sediment discharge in the Lower Irrawaddy basin in Myanmar.

5.2 Material and method

The study was carried out through integrated application of a GIS and RS approach. The following step-wise procedures were adopted to meet the information requirements for monitoring the land-use changes of the study area. Analysis of data was accomplished through integrated use ENVI (version 4.7) and Arc GIS (version 9.3) software packages along with Microsoft office analytical tools. The existing land use map of Myanmar is limited. This study made use of documents of Global and Regional land use map, Google

Earth imagery and some papers and maps about Myanmar land use and land cover change and forest cover change. The data collected by field survey and available Satellite images and maps for the lower Irrawaddy basin are listed in Table 5.1.

Table 5.1 Data sources of land use /cover change analysis

Data Source	**Data**	**Year**	**Description**
Map	Topographic Map	1955	Scale:1:250000
Map	Topographic Map	2003	Scale:1:50000
Document	Statistical year Book	2006	
	Statistical year Book	2009	
	Myanmar Forestry Report	2009	
	Myanmar Agricultural Atlas (FAO)	2002	
	Myanmar Survey Department Project Report	2003	
	HYDRO1k Database (USGS)		
			Path/row
Satellite image	Landsat Thematic Mapper (TM)	1989	133-46
	Landsat Enhanced Thematic Mapper (ETM+)	1999	133-47
	Landsat 7 SLC–On	2003	133-48
	Landsat 7 SLC–Off	2010	134-46
			134-47
Ground Reference	73 points	2011	field survey(GPS)

The Irrawaddy basin database and shape file is retrieved from HYDRO1k Database (USGS). The global drainage basins data derived from a global 1-km digital elevation model (DEM) has been developed by U.S. Geological Survey. HYDRO1k is a geographic database developed to provide comprehensive and consistent global coverage of topographically derived data sets, including streams**,** drainage basins and ancillary layers derived from the USGS 30 arc-second Digital Elevation Model of the world. The HYDRO1k package provides, for each continent, a suite of six raster and two vector data sets. These data sets cover many of the common derivative products used in hydrologic analysis. The raster data sets are the hydrologically correct DEM**,** derived flow directions, flow accumulations, slope, aspect, and a compound topographic index**.** Delineation of the Irrawaddy River basin and its sub-basins was adopted from a procedure for continental basin delineation and codification, based on a geographic database providing comprehensive and consistent global coverage of topographically derived data sets at a resolution of 1 km (HYDRO1k). The flow chart for methodology and procedure for land use/ cover classification is shown in Figure 5.1. Basic information of primary and secondary data was first extracted from the materials before converting to the digital format. The different processing steps follow the flow chart used for the land use classification. The land use/land cover map of shows categories such as crop land, barren land, forest lands, floodplain vegetation and water, etc. It also shows the procedure of land cover classification and image accuracy using a confusion matrix. The result shows the ground truth pixels and overall image accuracy and user accuracy percentage for each image.

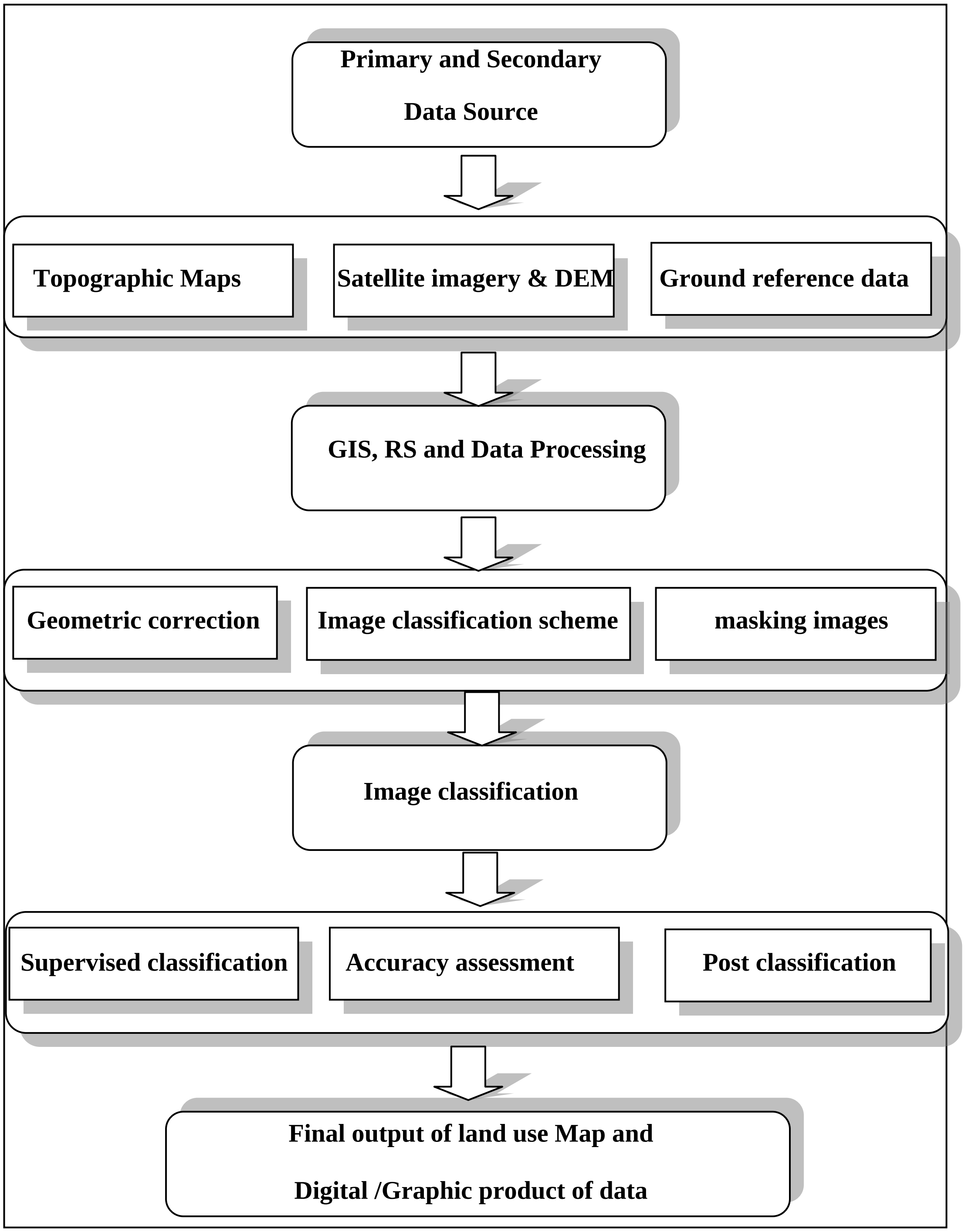
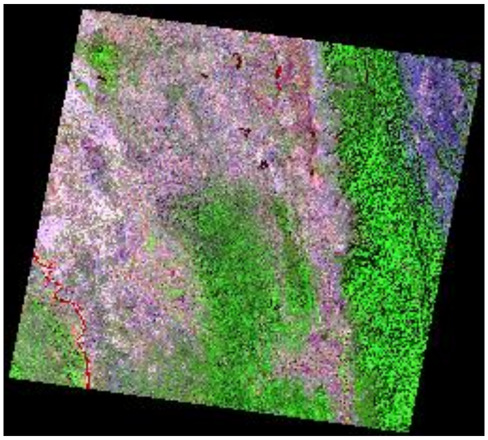
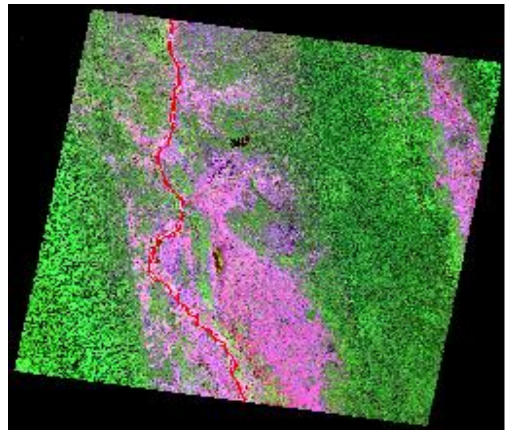


Figure 5.1 Flow chart of study methodology and procedure for land use/ cover classification

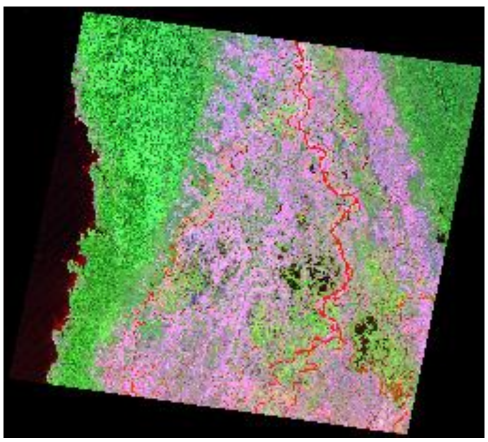
This study developed a methodology to map and monitor land cover change using multi-temporal Landsat Thematic Mapper (TM)and the Enhanced Thematic Mapper Plus (ETM+) of the Lower Irrawaddy basin for 1989 (Figure 5.2), 1999 (Figure 5.3), and 2003 (Figure 5.4) and 2010 (Figure 5.5). Land-use/cover mapping is achieved through interpretation of Landsat TM satellite images of twenty-one year time series (1989 to 2010) and using GIS and RS. Using a Land use/cover classification system, the land-use and land-covers are classified as forest land, water bodies, agricultural land and barren land and floodplain vegetation. The land-use/cover maps were produced by using supervised image classification technique based on the Maximum Likelihood Classifier. Error matrices as cross tabulations of the mapped class to the reference class were used to assess classification accuracy. Overall accuracy, user and producer accuracy, and the Kappa statistic were then derived from the error matrices.



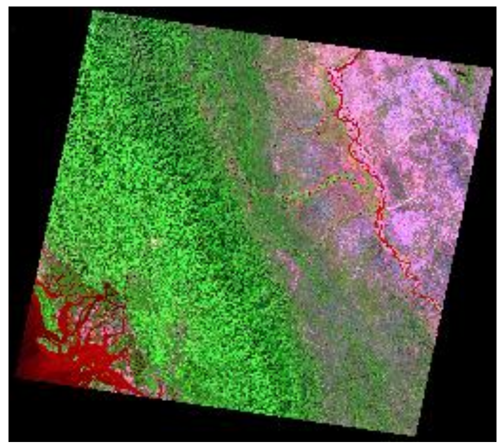
Landsat TM p133r46 (1989)



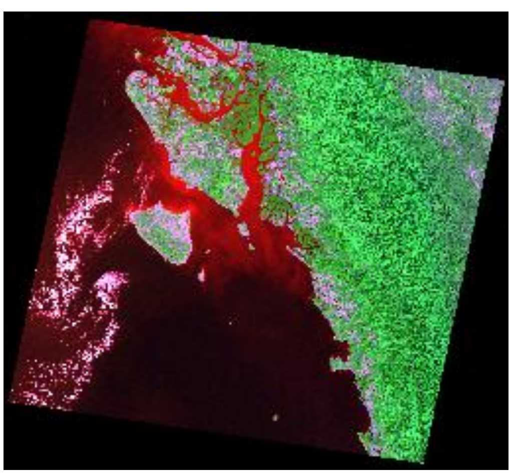
Landsat TM p133r47 (1989)



Landsat TM p133r48 (1989)

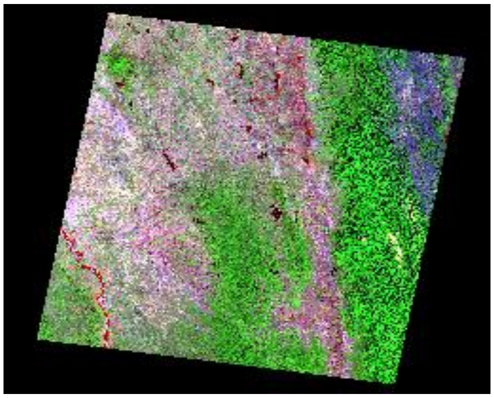


Landsat TM p134r46 (1989)

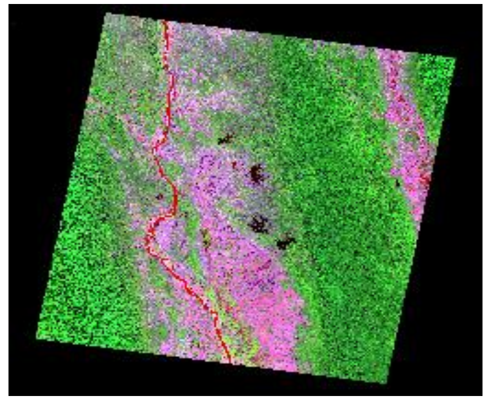


Landsat TM p134r47 (1989)

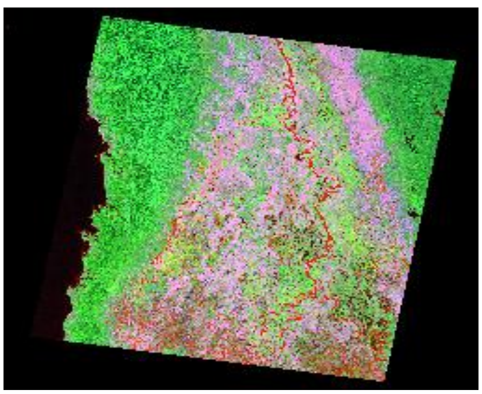
Figure 5.2 Landsat TM 1989 false colour images covering the lower Irrawaddy basin



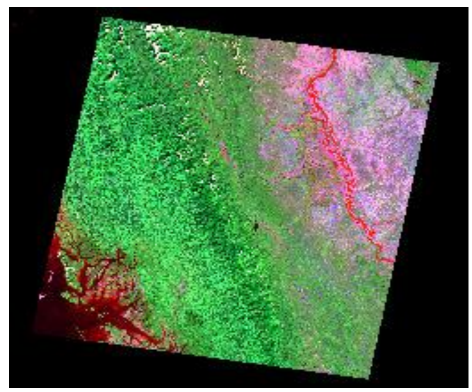
Landsat TM p133r046 (1999)



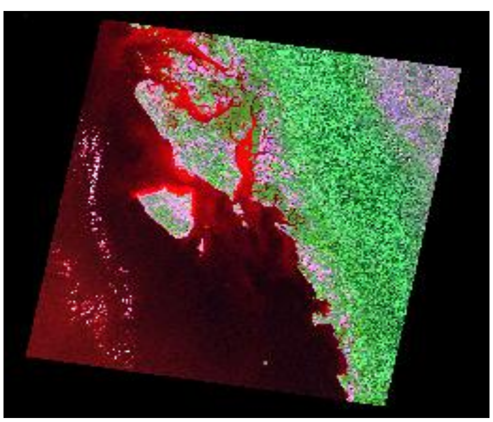
Landsat TM p133r047 (1999)



Landsat TM p133r048 (1999)

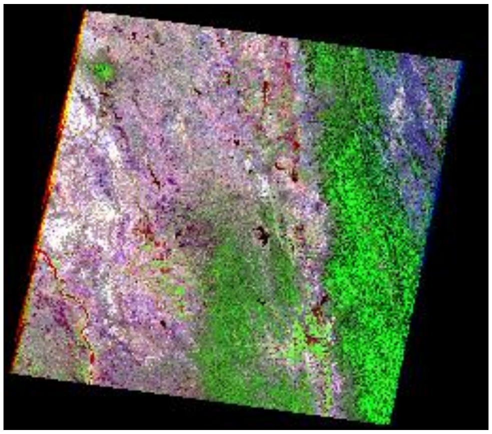


Landsat TM p134r046 (1999)

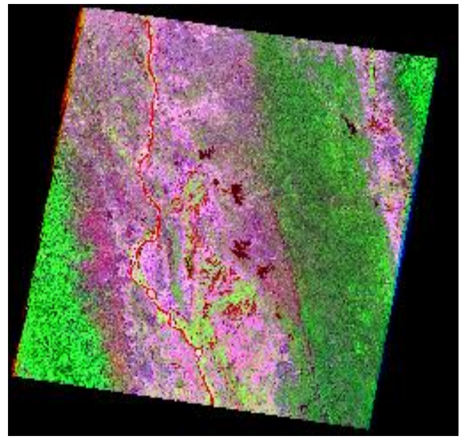


Landsat TM p134r047 (1999)

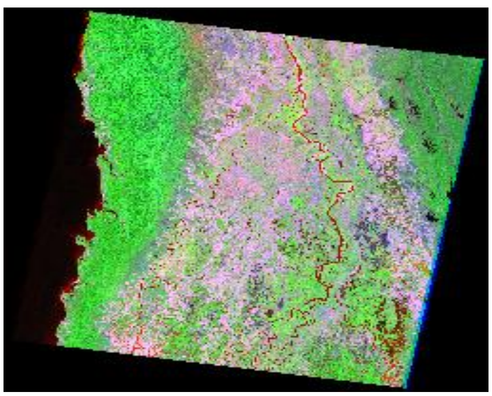
Figure 5.3 Landsat TM 1999 false colour images covering the lower Irrawaddy basin



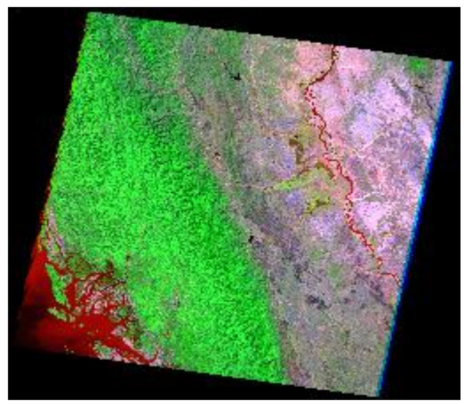
Landsat L71133046 (2003)



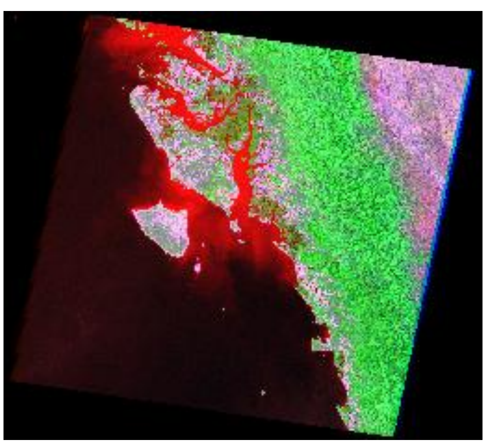
Landsat L71133047 (2003)



Landsat L71133048 (2003)

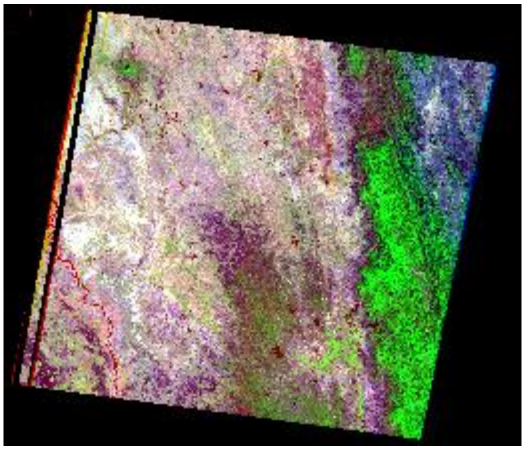


Landsat L71134046 (2003)

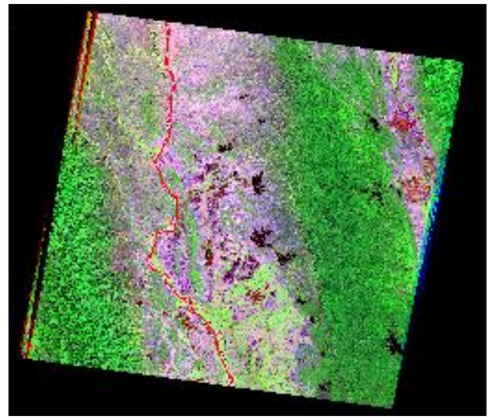


Landsat L71134047 (2003)

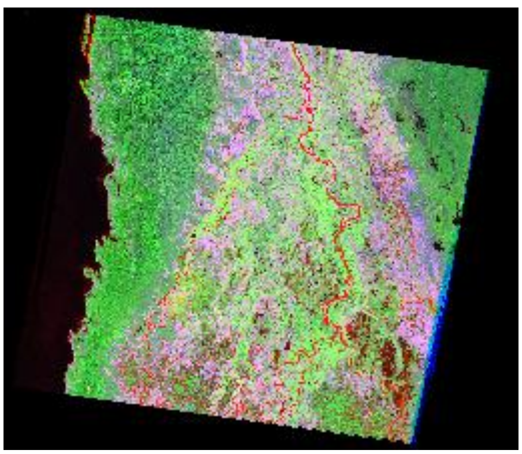
Figure 5.4 Landsat 7 SLC-On 2003 false colour images covering the lower Irrawaddy basin



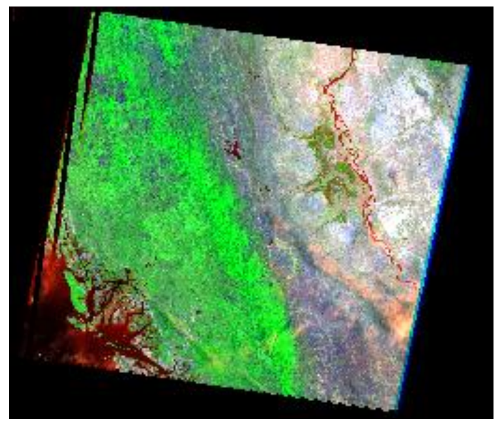
Landsat L71133046 (2010)



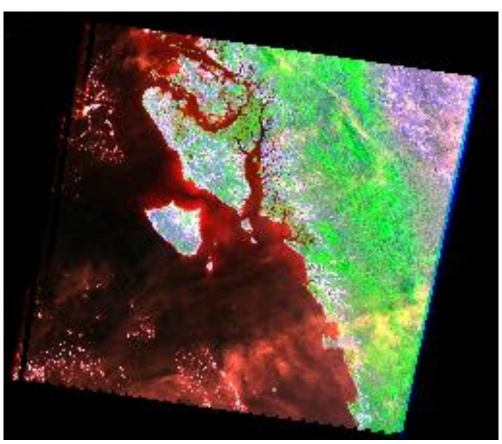
Landsat L71133047 (2010)



Landsat L71133048 (2010)



Landsat L71134046 (2010)

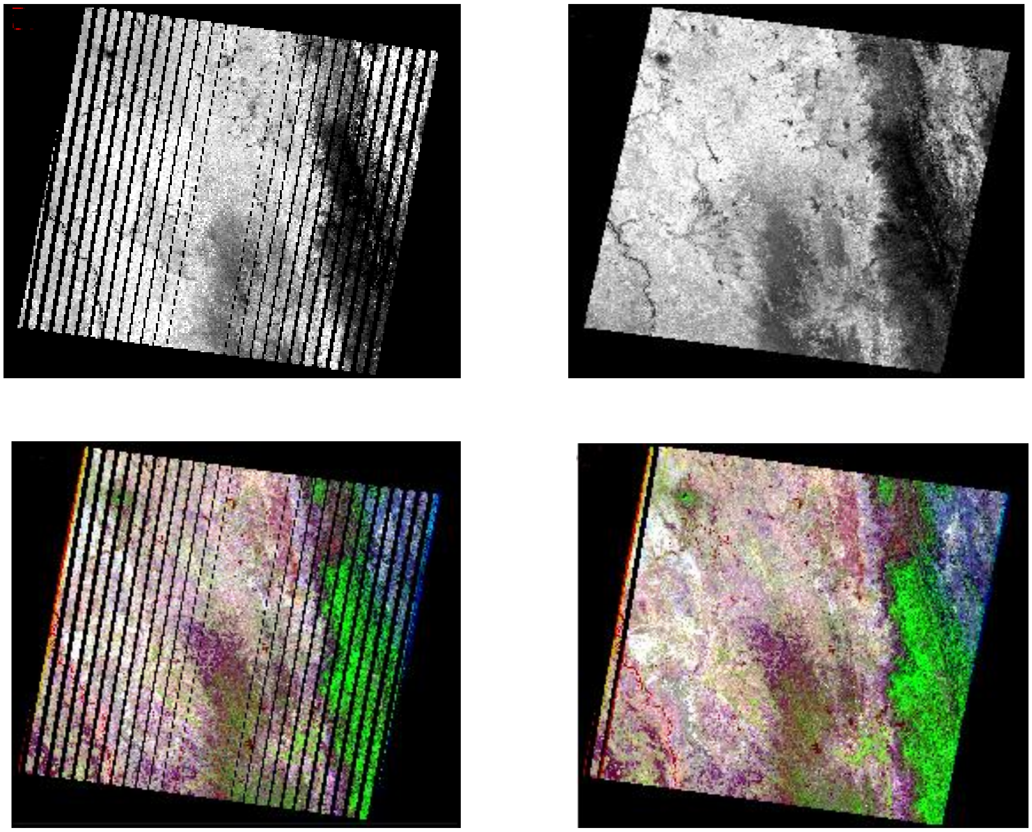


Landsat L71134047 (2010)

Figure 5.5 Landsat 7 SLC-Off 2010 false colour images covering the lower Irrawaddy basin

5.3 Satellite image processing

Satellite images of LANDSAT 7 ETM+ (Enhanced thematic Mapper plus) were downloaded from US Geological Survey in consideration of coverage, cloud cover, resolution and product format. The images were acquired in 5 scenes (each with eight bands) path 1330 - row 46, path 1330- row 47 , path 1330- row 48, path 1340- row 46, path 1340- row 47 for 1989, 1999, 2003 and 2010 covering the whole area of the lower Irrawaddy catchment. The pixel size are 28.5 m x 28.5 m for bands 1, 2, 3, 4, 5 and 7, 57 m x 57 m for thermal band 6 and 14.25 m x 14.25 m for panchromatic band 8. All are in GeoTIFF format. The Landsat image of 1989, 1999 and 2003 scenes are of quite good quality with more than 90% clear of cloud cover. However, the, 2010 scenes require some gap-filling at the image processing stage. In this study, Landsat TM (Figure 5.2), Landsat ETM+ (Figure 5.3), Landsat 7 SLC-On (Figure 5.4) and Landsat 7 SLC-Off (Figure 5.5) images are used for land cover classification. However, Landsat 7 experienced a Scan Line Corrector (SLC) problem in May 2003. The SLC problem causes individual scan lines to alternately overlap and then leave large gaps at the edges of the image. In order to obtain a useable image for between the dates 2003 and 2010, a procedure of interpolation and mosaic of overlapping scenes is employed. This procedure uses gap fill software to estimate the value of missing data pixels (Fig 5.6).



(a) Scan line gap with Landsat (b) After gap filling Landsat

Figure 5.6 Landsat L71133046 (2010) image displayed before and after gap filling

The USGS Earth Resources Observation and Science (EROS) Center developed the infrastructure to implement a production capability for multi-scene (same path/row) gap-filled products in an effort to improve the usability of ETM+ data acquired after the SLC failure. The areas with gaps in one scene can often be filled using data in overlapping scenes taken at nearly the same time as the 2003 images. This study used the gap-fill software to use the 2010 images.

5. 4 Procedure of land use/ cover classification

Land use information has been obtained from various sources of time series and spatial and temporal resolution. Here, the analysis of land use/cover classification used available Landsat images for the years 1989, 1999, 2003 and 2010. Reflectance data of the ROI pixel was the dependent variable for image value. The classification system used to select the ROI is compatible with other maps that have been used in the past because it is important to compare changes. The Land Use and Land Cover classification system used in this study is defined by United States Geological Survey (USGS) Land use/cover classification system (Anderson et al., 1976) which started in 1976 a programme to develop maps using aerial photography and interpretation of remotely sensed images (Campbell, 2002). The system used by USGS features the level one classification which is suitable for large-scale resolution. The produced ROI were classified into categories of urban or built-up land, forest land, water, agriculture, barren land, flood plain vegetation and sand bar. However, field surveying is used to re-check the actual land use in study area for image interpretation of land use classification. Several ground control points were checked for actual land use during the field work visits. Image enhancement was attempted to look at the differences among the scenes acquired on different dates.

A false colour composite image of bands 2, 4 and 7 was used in vegetation interpretation. This combination contains one band from each of the three spectral zones: the visible (bands 1, 2, and 3), near-infrared (band 4) and mid-infrared (bands 5 and 7). Insignificant differences were observed among them, which is probably due to the small time span between the three scenes. In the Landsat TM, ETM+, Landsat 7 SLC-On and Landsat 7

SLC-Off, the resolution of some bands is not clear enough for land cover classification. The high spatial resolution has been increasingly used for urban land use classification but the shadow problem often leads to poor classification accuracy based on pixel spectral based classification. In the study area especially, urban and rural settlement is complex with abundant tree shade and a mixture with other land cover, particularly the close proximity of buildings, agricultural fields and trees. An example of the difficulty of segregating land use around settlements is illustrated by the town of Pyay, the largest urban area in the Lower Irrawaddy (Figure 5.7). Therefore, since urbanization is not of direct concern to the present study, the image classifications of rural and urban settlement have not been included in the estimation in the Lower Irrawaddy basin land cover classification.

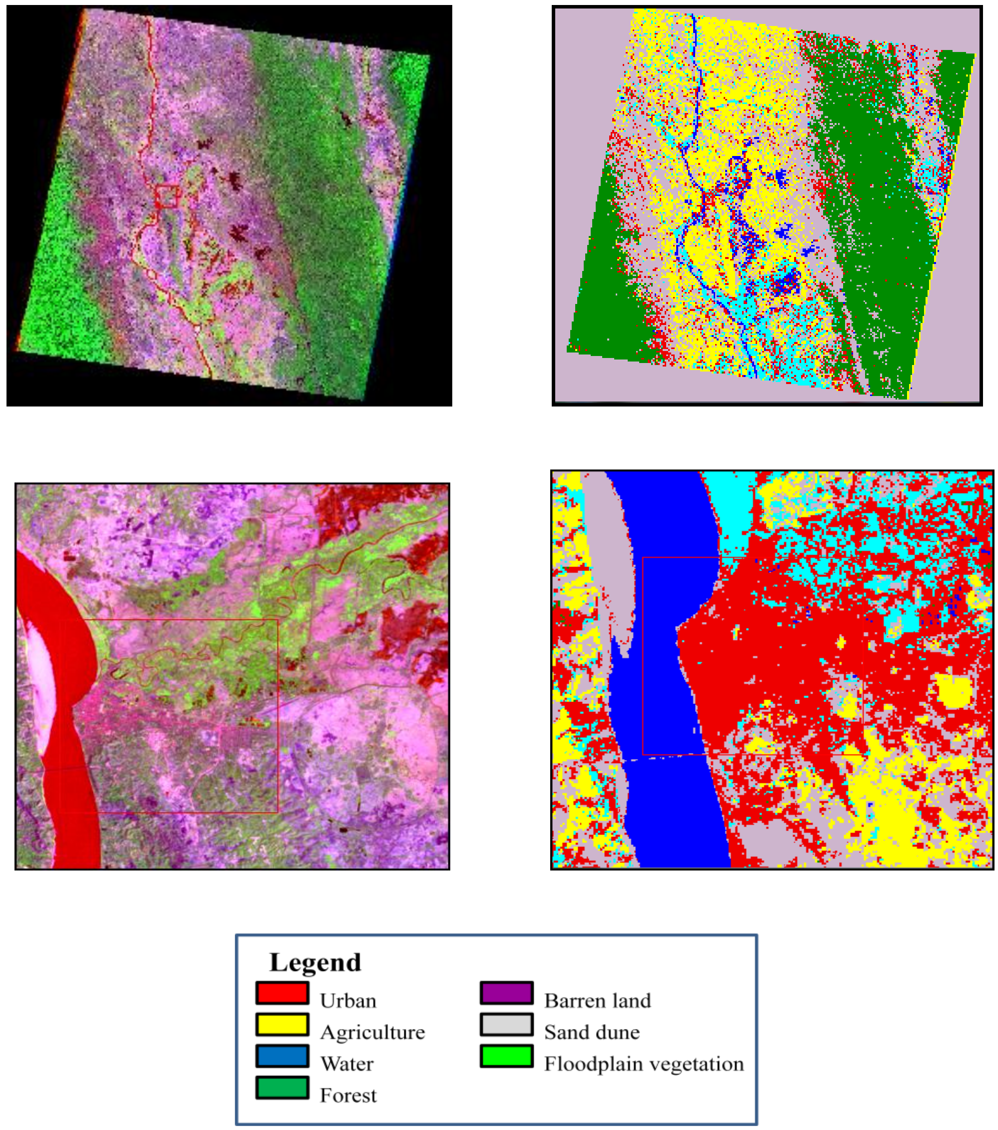


Figure 5.7 Landsat images displayed mixed urban settlement and other land cover classification in study area

5. 5 Pre-classification and post-classification

There are two types of classification of image and data output involving either pre-classification or post- classification. Digital image classification procedures were applied to the mosaicked images of the Landsat TM and 7 ETM+ data using the supervised classification method (Deppe, 1998; Congalton et al. 1998). The supervised classification method requires the user to develop the spectra signatures of known categories, while the software assigns to each pixel in the image a category to which its signature is most similar. The maximum likelihood algorithm with equal probability of occurrence was used in the classification. In the maximum likelihood method, the distribution of reflectance values in a training site is described by a probability density function, developed on the basis of statistics. This method uses the training data as means of estimating and classification. However, most of Landsat-7 satellite images have some high cloud cover and gaps in the images after 2003 are problematic. The Lower Irrawaddy basin area is covered by five Landsat scenes. Therefore a total of 20 images were collected with five images each from the years 1989, 1999, 2003 and 2010. The timing of each acquired image is from January, February and March so that each image is compared in the dry season and year-to-year variability in soil moisture and vegetation growth is minimized (Table 5.2). As Myanmar is an agriculturally based country, the dry months of January to March cover the period for harvesting winter crops and planting the summer crops. Satellite images may be strongly influenced by seasonality of climate and land surface conditions. Landsat 7 images are currently operated as a primary satellite. Land use and land cover change represent the integration of elements of the resource base of using seasonal characteristics of land surface reflectance measured with time series.

Therefore, Ladsat-7 images were used for spectral analysis for land use and land cover classification for lower Irrawaddy basin.

Table 5.2 Band Characteristics of Landsat MSS, TM and ETM+ images

Data type	Spectral resolution (μm)	Nominal spectral location	Ground resolution (m)	Scene of Time
Landsat MSS	Band 1 (0.500-0.600)	Green	79	
	Band 2 (0.600-0.700)	Red	79	
	Band 3 (0.700-0.800)	Near IR	79	
	Band 4 (0.800-1.100)	Near IR	79	
Landsat TM	Band 1 (0.45-0.515)	Blue	30	etp133r46_4t19890116
	Band 2 (0.525-0.605)	Green	30	etp133r47_4t19890116
	Band 3 (0.63-0.690)	Red	30	etp133r48_4t19890116
	Band 4 (0.750-0.900)	Near IR	30	etp134r46_4t19890123
	Band 5 (1.550-1.750)	Shortwave IR	30	etp134r47_4t19890123
	Band 6 (10.40-12.50)	Thermal IR	60	
	Band 7 (2.090-2.350)	Shortwave IR	30	
Landsat ETM+	Band 1 (0.45-0.515)	Blue	30	elp133r046_7t19991230
	Band 2 (0.525-0.605)	Green	30	elp133r047_7t19991230
	Band 3 (0.63-0.690)	Red	30	elp133r048_7t19991230
	Band 4 (0.750-0.900)	Near IR	30	elp134r046_7t20011124
	Band 5 (1.550-1.750)	Shortwave IR	30	elp134r047_7t20020111
	Band 6 (10.40-12.50)	Thermal IR	60	
	Band 7 (2.090-2.350)	Shortwave IR	30	
	Band 8 (0.520-0.900)	Panchromatic	15	
	Above Landsat ETM+ SLC-On			LE71330462003055SGS00 LE71330472003055SGS00 LE71330482003055SGS00 LE71340462003062SGS00 LE71340472003062SGS00
	Above Landsat ETM+ SLC-Off			LE71330462010058SGS00 LE71330472010010SGS00 LE71330482010010SGS00 LE71340462010097SGS00 LE71340472010097SGS00

5. 6 Image classification and Results

A supervised classification requires analysis of the selected training area. There are many techniques for assigning pixels to informational classes. The Maximum Likelihood classifier is one of the most popular methods for land cover classification in Remote Sensing and is widely used. Maximum likelihood estimates of the parameters are computed, and individual pixels are assigned to the class which maximizes the likelihood function of the data set. The Maximum Likelihood classification was used in the study. The advantages and disadvantages of the Maximum Likelihood classification are shown in Table 5.3.

Table 5.3 Advantages and disadvantages of the Maximum Likelihood classification

Advantages	**Disadvantages**
- it takes the variability of the classes into account by using the covariance matrix - the most accurate algorithm when using the Erdas IMAGINE image processing software - generally produces the most accurate classification - the method is statistically well founded	- the computation time of an extensive equation is long time to compute - tends to over classify classes with large spectral variability - the result is dependent on the model of evolution used

The Maximum Likelihood decision method is widely used when pattern recognition is applied to remote sensing data analysis. A supervised Maximum likelihood classification was performed using the developed signatures of the Land use/cover categories of Water, Forest and Agriculture, Barren land and Flood plain vegetation areas. Lastly classified image was exported to Arc View GIS software for better presentation. The classified result of land use /land map of the Lower Irrawaddy basin obtained from the LANDSAT 7 ETM+ satellite images of 1989 (Figure 5.2), 1999 (Figure 5.3), 2003 (Figure 5.4) and 2010 (Figure 5.5). The ground reference data of 73 GPS points were collected for the Irrawaddy basin (Figure 5.8). The points were mainly collected close to the riparian zone of the Irrawaddy River within the study area. The ground truth reference helps for classification of land use type accuracy. Not all land use types can be seen from ground truth point collection during field work as this was concentrated close to the river and more distant tributaries could not be visited. However, more reference data were derived from old land use maps and Google earth images. After image classification, supervised and unsupervised classification methods are needed ENVI software is useful for land cover classified images. Post-classification was computed for selected classifying images and output to vector file and then exported to a text file. The data are imported from text file into Microsoft excel and can be converted to other units.

Table 5.4 Land use /cover classification scheme

Category	Description
Water	Rivers, Streams, Ponds, Reservoirs
Forest land	Natural forest, plantation, orchard
Agricultural land	Seasonal crops
Barren land	Rocks, sands, bare soil ,sand bars
Floodplain vegetation	Others

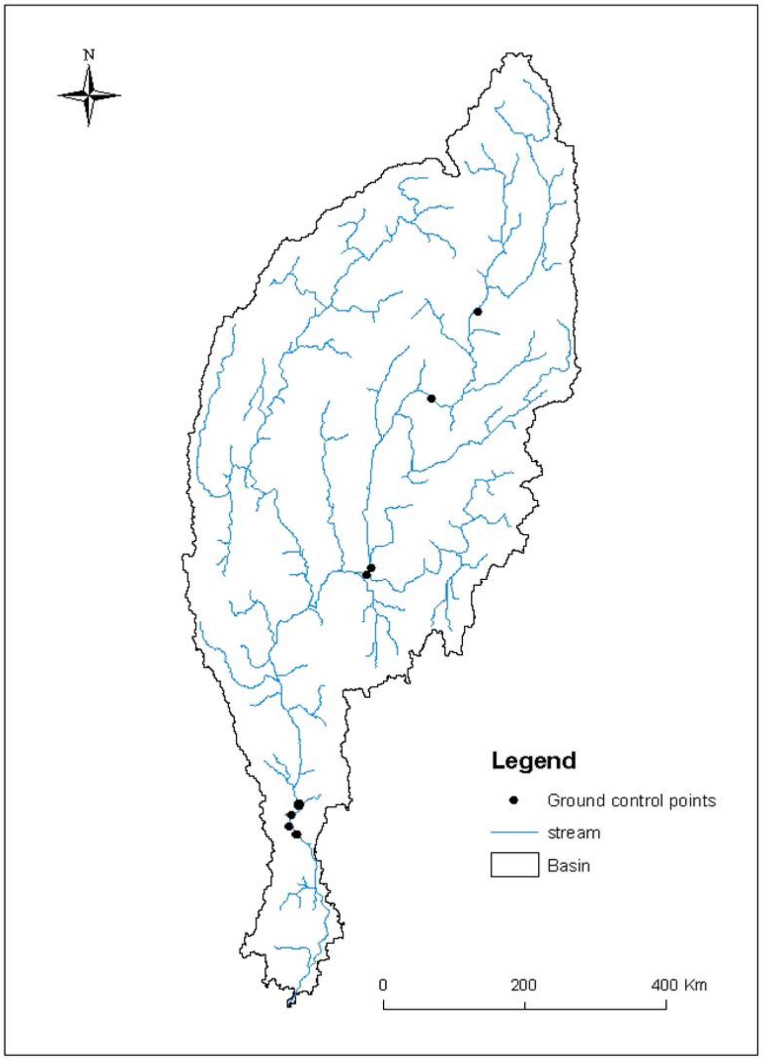
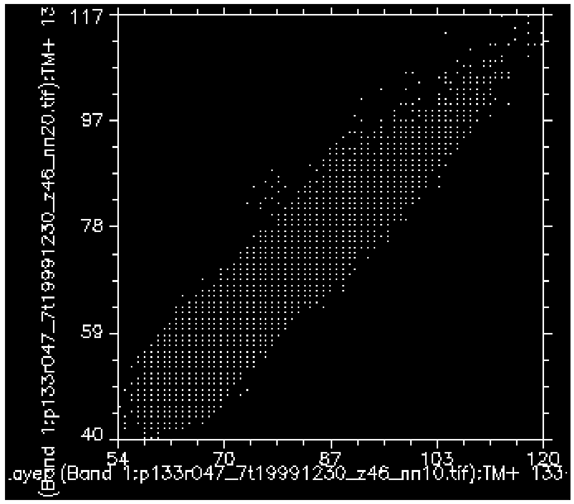


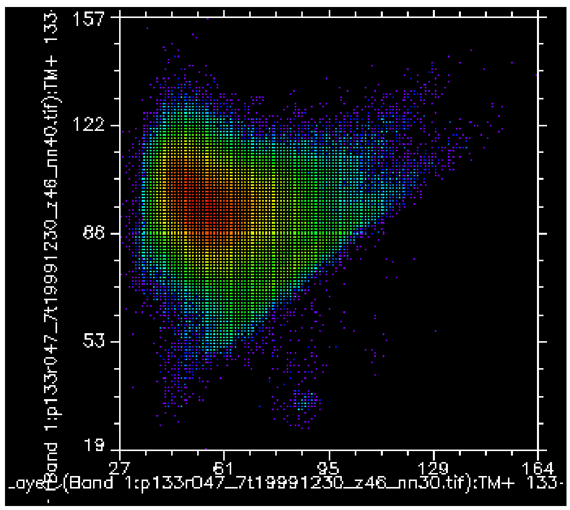
Figure 5.8 Ground reference points collected in Irrawaddy basin

Image classification method can be divided into supervised and unsupervised classification. This study adopted supervised classification using a predefined training area of homogeneous surface land cover. In this procedure several steps are involved in applying supervised classification and generating maximum likelihood classifier. Maximum likelihood classification is used to distribute pixels within classes. For each pixel in the image, this function calculates the probability that the pixel is of that class. The training is undertaken using ENVI software (ENVI is the short name for Environment for the Visualization of Images) (which uses a region of interest (ROI) of a particular land cover to assign similar pixels within the classified area. The digital number (DN) is a value for pixels for each land cover classification within the study area. The class of land cover type is the observed frequency of each DN value for that class. The DN values for the training areas of each land cover type in lower Irrawaddy basin image are shown in (1989), (1999), (2003) and (2010). Land cover/ use mapping and classification algorithms require detailed information about the spectral separability between land cover types.

The correlation of each type is computed with the spectral separability Jeffries-Matusita Distance (J-M) algorithm (ITT Visual Informational Solutions, User Guide, 2009). The J-M distance is a function of separability that directly related to the probability of how good a resultant classification will be. The J-M distance and Transformed Divergence can be directly calculated with ENVI, where, TD scaled between 0 and 2 range. In ENVI calculation the J-M distance is squared to range between 0 and 2 and as such the square root of output classification result. Whereas selected class of values of less than 2 represent and regarding good separability in the land cover classification. Tables 5.5 and Table 5.6 show the sample of Jeffries-Matusita Distance (J-M) algorithm for the image path 133- row 48, 1989 and path 133- row 47, 2010. The image pairs and the classification result is 1.5 to 2.0. Therefore accuracy of the classification is acceptable and the result can be used for land cover classification analysis.



(a) 2 D scatter plot of band 1 and band 2



(b) 2 D density plot of band 3 and band 4

Figure 5.9 Two Dimensional scatter plot for ETM+ elp133r47 (1999)

The histograms for data points included in training area of classification of sample image ETM+ elp133r47 (2009) are shown in Figure 5.9. DN values are normally distributed in each band. The spectral separability of training sets with two bands was plotted, band1 against band 2, band 3 against band 4 using a two-dimensional scatter plot.

Table 5.5 A sample of Jeffries-Matusita Distance (J-M) algorithm (1989 image)

InputFile:TM133-48_89			
ROI Name:(Jeffries-Matusita, Transformed Divergence)			
Water		7119 points:	
	Forest land	15296 points:	(1.99527785-2.00000000)
	Agricultural land	7037 points:	(2.00000000-2.00000000)
	Barren land	11250 points:	(1.99227800-2.00000000)
	Floodplain vegetation	4959 points:	(1.99999903-2.00000000)
Forest land		15296 points:	
	Water	7119 points:	(1.99527785-2.00000000)
	Agricultural land	7037 points:	(1.99963016-1.99999998)
	Barren land	11250 points:	(1.91759660-1.99999974)
	Floodplain vegetation	4959 points:	(1.74796494-1.85386388)
Agricultural land		7037 points:	
	Water	7119 points:	(2.00000000-2.00000000)
	Forest land	15296 points:	(1.99963016-1.99999998)
	Barren land	11250 points:	(1.56529520-1.84752020)
	Floodplain vegetation	4959 points:	(1.99942823-2.00000000)
Barren land		11250 points:	
	Water	7119 points:	(1.99227800-2.00000000)
	Forest land	15296 points:	(1.91759660-1.99999974)
	Agricultural land	7037 points:	(1.56529520-1.84752020)
	Floodplain vegetation	4959 points:	(1.96626912-1.99998273)
Floodplain vegetation		4959 points:	
	Water	7119 points:	(1.99999903-2.00000000)
	Forest land	15296 points:	(1.74796494-1.85386388)
	Agricultural land	7037 points:	(1.99942823-2.00000000)
	Barren land	11250 points:	(1.96626912-1.99998273)
Pair Separation (least to most)			
Agricultural land 7037 points: and Barren land 11250 points-1.5652952			
Forest land 15296 points: and Floodplain vegetation 4959 points-1.74796494			
Forest land 15296 points: and Barren land 11250 points-1.9175966			
Barren land 11250 points: and Floodplain vegetation 4959 points-1.96626912			
Water 7119 points: and Barren land 11250 points-1.992278			
Water 7119 points: and Forest land 15296 points-1.99527785			
Agricultural land 7037 points: and Floodplain vegetation 4959 points-1.99942823			
Forest land 15296 points: and Agricultural land 7037 points-1.99963016			
Water 7119 points: and Floodplain vegetation 4959 points-1.99999903			
Water 7119 points: and Agricultural land 7037 points-2.00000000			

Table 5.6 A sample of Jeffries-Matusita Distance (J-M) algorithm (2010 image)

Input File: 133-47_2010			
ROI Name:(Jeffries-Matusita Transformed Divergence)			
Water		6323points:	
	Forest land	6746 points:	(1.97080093-1.99999883)
	Agricultural land	3067 points:	(1.99927806-2.00000000)
	Barren land	8239 points:	(1.90125043-1.99970312)
	Floodplain vegetation	4202 points:	(1.99986391-2.00000000)
Forest land		6746 points:	
	Water	6323 points:	(1.97080093-1.99999883)
	Agricultural land	3067 points:	(1.99743735-2.00000000)
	Barren land	8239 points:	(1.90811764-1.99999984)
	Floodplain vegetation	4202 points:	(1.99720761-2.00000000)
Agricultural land		3067 points:	
	Water	6323 points:	(1.99927806-2.00000000)
	Forest land	6746 points:	(1.99743735-2.00000000)
	Barren land	8239 points:	(1.86460705-2.00000000)
	Floodplain vegetation	4202 points:	(1.98879068-1.99999884)
Barren land		8239 points:	
	Water	6323 points:	(1.90125043-1.99970312)
	Forest land	6746 points:	(1.90811764-1.99999984)
	Agricultural land	3067 points:	(1.86460705-2.00000000)
	Floodplain vegetation	4202 points:	(1.99098733-2.00000000)
Floodplain vegetation		4202 points:	
	Water	6323 points:	(1.99986391-2.00000000)
	Forest land	6746 points:	(1.99720761-2.00000000)
	Agricultural land	3067 points:	(1.98879068-1.99999884)
	Barren land	8239 points:	(1.99098733-2.00000000)
Pair Separation (least to most)			
Agricultural land 3067points and Barren land 8239 points- 1.86460705			
Water 6323 points and Barren land 8239 points -1.90125043			
Forest Land 6746 points and Barren Land 8239 points -1.90811764			
Water 6323 points and Forest land 6746 points-1.97080093			
Agricultural land 3067 points and Floodplain vegetation 4202 points-1.98879068			
Barren land 8239 points and Floodplain vegetation 4202 points-1.99098733			
Forest land 6746 points and Floodplain vegetation 4202 points-1.99720761			
Forest land 6746 points and Agricultural land 3067 points-1.99743735			
Water 6323 points and Agricultural land 3067 points-1.99927806			
Water 6323 points and Floodplain vegetation 4202 points-1.99986391			

The classification scheme was based on the land cover and land use classification system developed for interpretation of remote sensing data at various scales and resolutions. The image classification was carried out in ENVI software. A supervised classification technique with Maximum Likelihood Algorithm was applied. The land-use/cover maps of 1989, 1999, 2003 and 2010 were produced by using supervised image classification technique based on the Maximum Likelihood Classifier and training samples. An independent sample of an average of polygons with about 30,000 pixels for each selected polygon was randomly selected from each classification to assess classification accuracies. Error matrices as cross-tabulations of the mapped class to the reference class were used to assess classification accuracy. Overall accuracy, user and producer accuracy, and the Kappa statistic were then derived from the error matrices. Following the classification of imagery from the years of 1989 to 2010 post-classification comparison change detection algorithm was used to determine changes in land cover. This is the most common approach to change detection and was successfully used to monitor land use changes in the Lower Irrawaddy basin. The post-classification approach provides "from-to" change information and the class of landscape transformations that have calculated. In accuracy assessment for supervised classification of Landsat image 1989, the overall accuracy was found to be 95.85 % and the Kappa coefficient to be 0.9464 (Table 5.7). In accuracy assessment for supervised classification of Landsat image 2010, the overall accuracy was found to be 91.66 % and the Kappa coefficient to be 0.8939 (Table 5.8). In the table A, B and C shows the ground reference data (pixels), ground reference data (percentage), commission and omission (pixels and percentage) for each land use classification type of water, forest land, agricultural land, barren land and floodplain vegetation. Table D shows the producer accuracy of pixels and user accuracy of pixels and percentage. All producer accuracy and user accuracy are above 91% in each image.

Table 5.7 Accuracy assessment for supervised classification Landsat 1989

A	Ground Reference data (Pixels)					
Class	Water	Forest land	Agricultural	Barren land	Floodplain vegetation	Total
Water	7016	0	0	23	1	7040
Forest land	7	14719	6	72	112	14916
Agricultural	0	5	6729	515	1	7250
Barren land	95	199	300	10557	86	11237
Floodplain	1	373	2	83	4759	5218
Total	7119	15296	7037	11250	4959	45661

B	Ground Reference data (Percent)					
Class	Water	Forest land	Agricultural	Barren land	Floodplain vegetation	Total
Water	98.55	0	0	0.2	0.02	15.42
Forest land	0.1	96.23	0.09	0.64	2.26	32.67
Agricultural	0	0.03	95.62	4.58	0.02	15.88
Barren land	1.33	1.3	4.26	93.84	1.73	24.61
Floodplain	0.01	2.44	0.03	0.74	95.97	11.43
Total	100	100	100	100	100	100

C Class	Commission (Pixels)	Omission (Pixels)	Commission (Percent)	Omission (Percent)
Water	24/7040	103/7119	0.34	1.45
Forest land	197/14916	577/15296	1.32	3.77
Agricultural	521/7250	308/7037	7.19	4.38
Barren land	680/11237	693/11250	6.05	6.16
Floodplain	459/5218	200/4959	8.8	4.03

D Class	Producer accuracy (Pixels)	User accuracy (Pixels)	Producer accuracy (Percent)	User accuracy (Percent)
Water	7016/7119	7016/7040	98.55	99.66
Forest land	14719/15296	14719/14916	96.23	98.68
Agricultural	6729/7037	6729/7250	95.62	92.81
Barren land	10557/11250	10557/11237	93.84	93.95
Floodplain	4759/4959	4759/5218	95.97	91.2
Kappa Coefficient = 0.9464				

Overall Accuracy= (43780/45661) 95.885 %

Table 5.8 Accuracy assessment for supervised classification Landsat 2010

A	**Ground Reference data (Pixels)**					
Class	Water	Forest land	Agricultural	Barren land	Floodplain vegetation	Total
Water	5964	32	0	41	1	6038
Forest land	42	6472	2	243	19	6778
Agricultural	50	51	2937	1157	17	4212
Barren land	252	178	97	6702	46	7275
Floodplain	15	13	31	96	4119	4274
Total	6323	6746	3067	8239	4202	28577

B	Ground Reference data (Percent)					
Class	Water	Forest land	Agricultural	Barren land	Floodplain vegetation	Total
Water	94.32	0.47	0	0.5	0.02	21.13
Forest land	0.66	95.94	0.07	2.95	0.45	23.72
Agricultural	0.79	0.76	95.76	14.04	0.4	14.74
Barren land	3.99	2.64	3.16	81.34	1.09	25.46
Floodplain	0.24	0.19	1.01	1.17	98.02	14.96
Total	100	100	100	100	100	100

C Class	Commission (Pixels)	Omission (Pixels)	Commission (Percent)	Omission (Percent)
Water	74/6038	359/6323	1.23	5.68
Forest land	306/6778	274/6746	4.51	4.06
Agricultural	1275/4212	130/3067	30.27	4.24
Barren land	573/7275	1537/8239	7.88	18.66
Floodplain	155/4274	83/4202	3.63	1.98

D Class	Producer accuracy (Pixels)	User accuracy (Pixels)	Producer accuracy (Percent)	User accuracy
Water	5964/6323	5964/6038	94.32	98.77
Forest land	6472/6746	6472/6778	95.94	95.49
Agricultural	2937/3067	2937/4212	95.76	69.73
Barren land	6702/8239	6702/7275	81.34	92.12
Floodplain	4119/4202	4119/4274	98.02	96.37

Kappa Coefficient = 0.8939

Overall Accuracy= (26194/28577) 91.66%,

5.7 Result and Discussion

In this section, changes between time series land cover types are analyzed. The lower Irrawaddy basin total area is 399962.40 km^2 and the 1989 (Figure 5.10), 1999 (Figure 5.11), 2003 (Figure 5.12), and 2010 (Figure 5.13), time series images of land cover types and percentages are shown in Table 5.9 in this section. Figure 5.14 and Figure 5.15 show the land cover classification changes and land cover changes area in the Lower Irawaddy basin. In 1989, the forest land cover type covered an area of 18515.0 km^2 and accounted for 46.33% of the total catchment. This was followed by barren land (12369.2 km^2 and 30.95%), Agricultural land (5554.8 km^2 and 13.95%), floodplain vegetation land (2895 km^2 and 7.25%) and Water bodies (629.6 km^2 and 1.57%). In 1999, the forest land cover type covered of 20710.4 km^2 and accounted for 51.82 % of the total catchment. There was followed by Agricultural land (7271.9km^2 and 18.20 %), Floodplain vegetation land (5590.3 km^2 and 13.99%), barren land (5405.3 km^2 and 13.53%) and Water bodies (984.5 km^2 and 2.46%). In 2003, the Barren land cover type was with area of 14984.8 km^2 and accounting for 37.50% of the total catchment. There was followed by Agricultural land (11572.1 km^2 and 28.96%), forest land (10278.6 km^2 and 25.72 %), and Floodplain vegetation land (2244.1 km^2 and 5.62%) and Water bodies (882.7 km^2 and 2.21%). In 2010, the Agricultural land cover type covered 13892.8 km^2 and accounted for 34.76% of the total catchment. This was followed by barren land (12053.9 km^2 and 30.16%), forest land (9483.9 km^2 and 23.73%), Floodplain vegetation land (3522.7 km^2 and 8.82%) and Water bodies (1009.1 km^2 and 2.53 %).

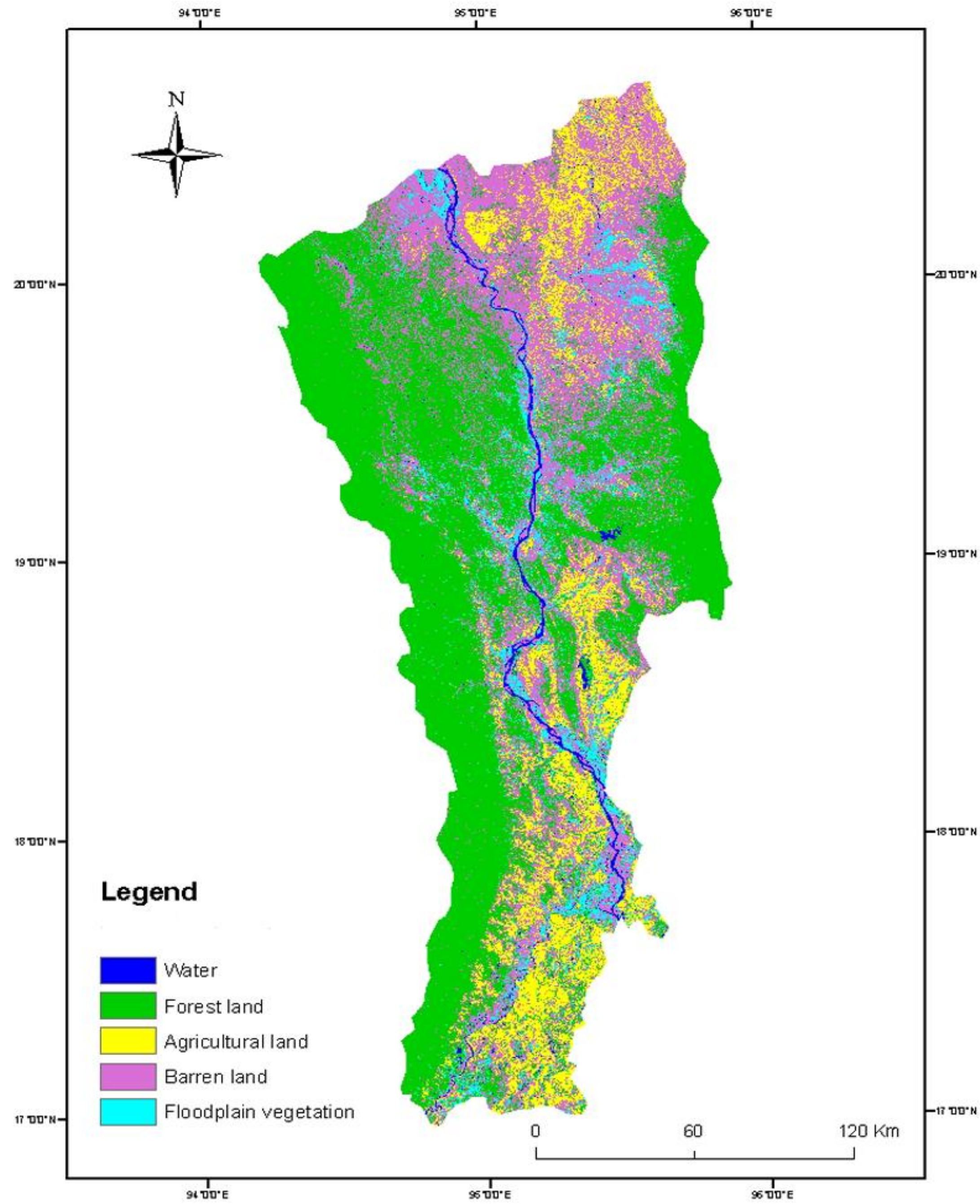


Figure 5.10 Land use and land cover of Lower Irrawaddy basin in 1989

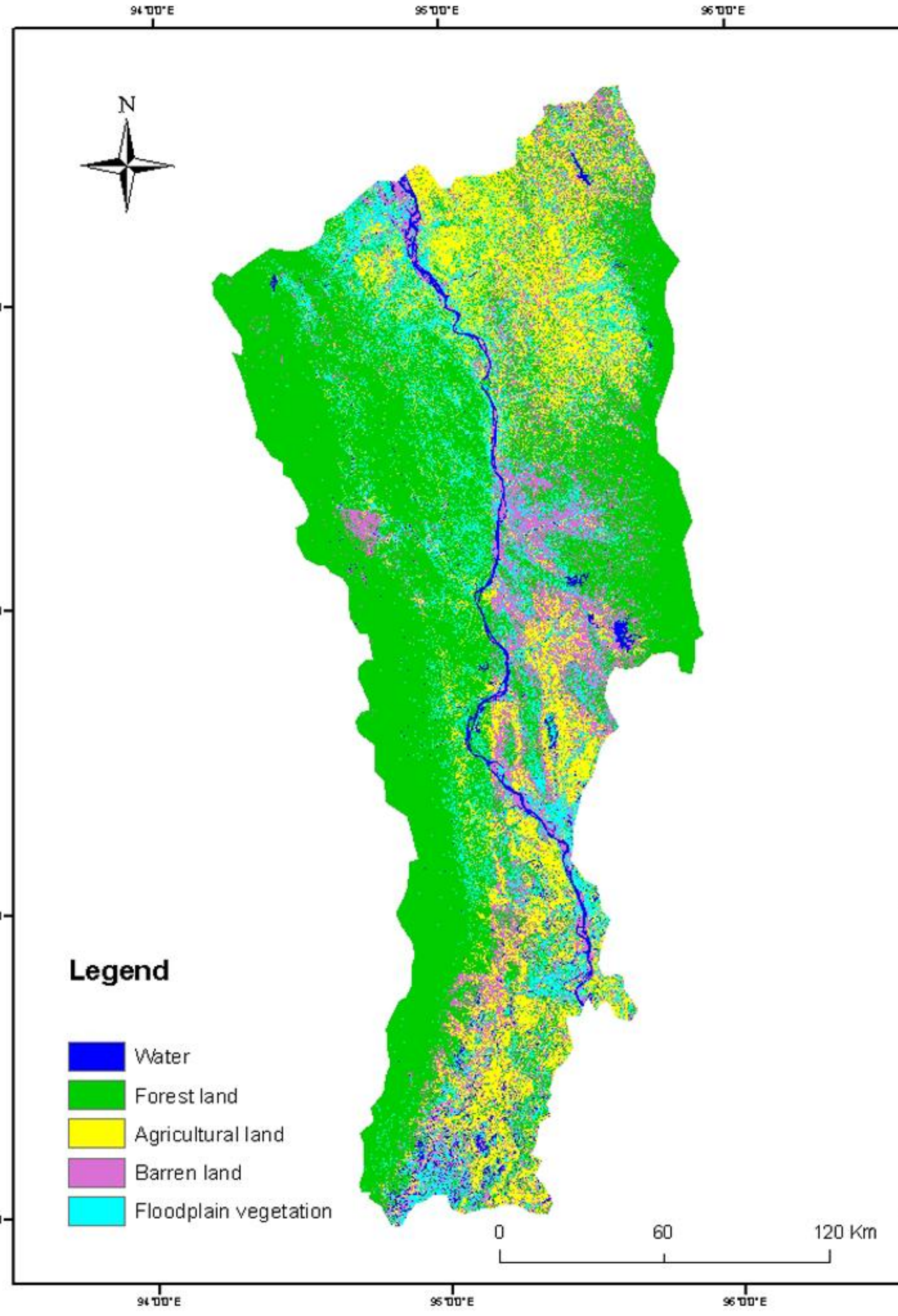


Figure 5.11 Land use and land cover of Lower Irrawaddy basin in 1999

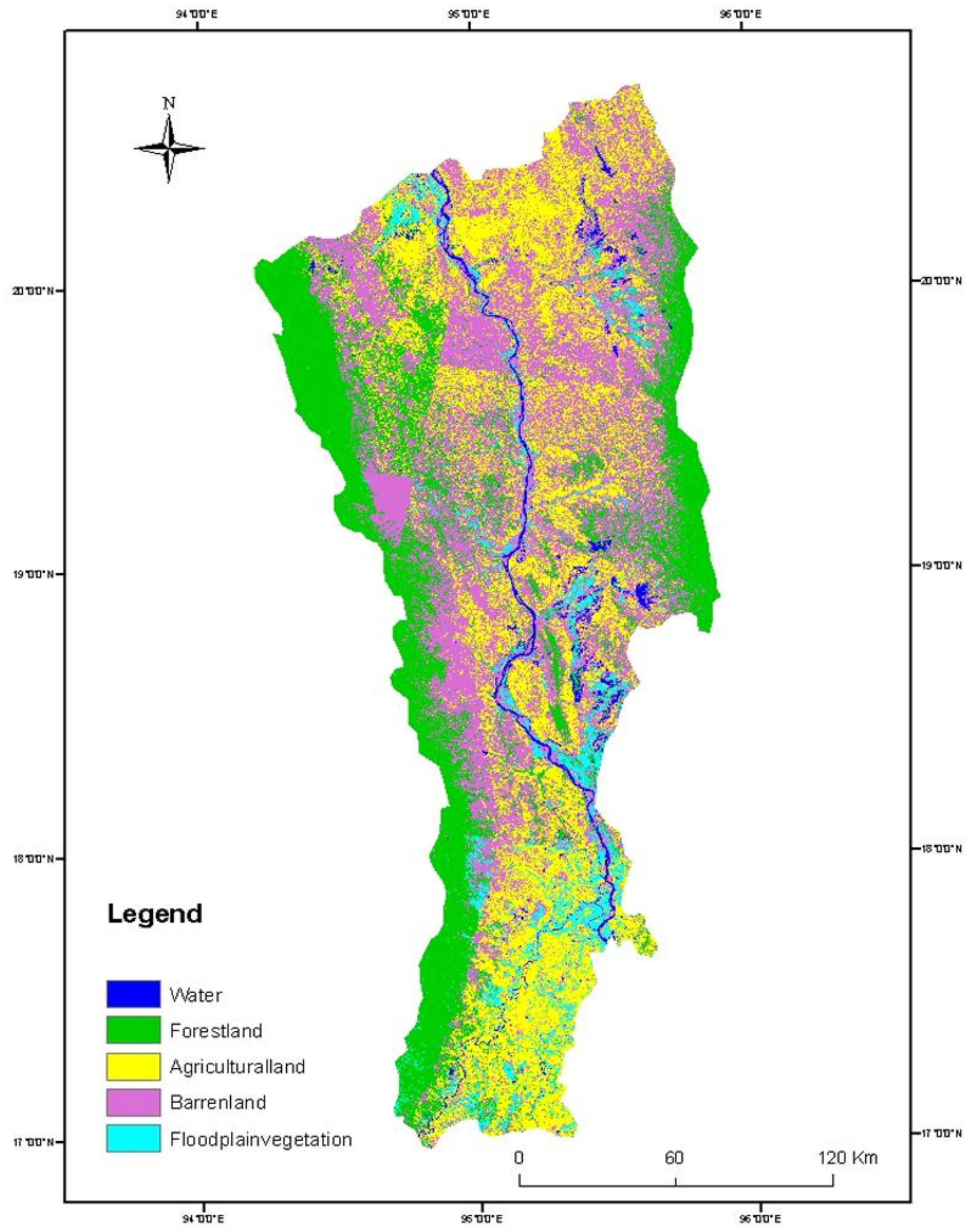


Figure 5.12 Land use and land cover of Lower Irrawaddy basin in 2003

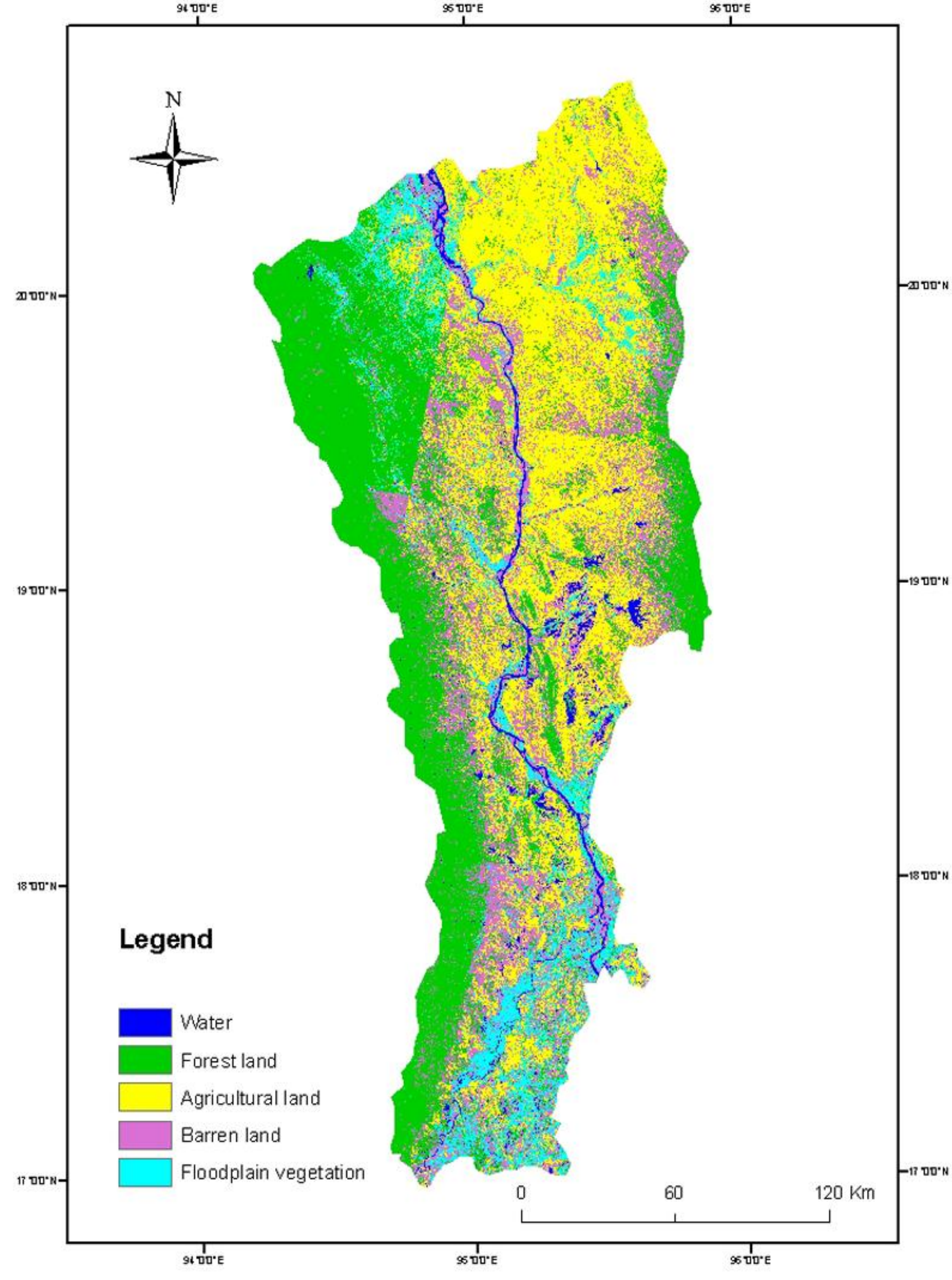


Figure 5.13 Land use and land cover of Lower Irrawaddy basin in 2010

Table 5.9 Land use /cover of Lower Irrawaddy basin in 1989, 1999, 2003 and 2010

	1989		1999		2003		2010	
Land use/cover	(Km^2)	(%)	(Km^2)	(%)	(Km^2)	(%)	(Km^2)	(%)
Water	628.60	1.57	984.48	2.46	882.73	2.21	1009.10	2.53
Forest land	18515.02	46.33	20710.39	51.82	10278.63	25.72	9483.90	23.73
Agricultural land	5554.31	13.90	7271.91	18.20	11572.05	28.96	13892.80	34.76
Barren land	12369.15	30.95	5405.33	13.53	14984.85	37.50	12053.90	30.16
Floodplain vegetation	2895.32	7.25	5590.29	13.99	2244.13	5.62	3522.70	8.82
Total	39962.40	100.00	39962.40	100.00	39962.40	100.00	39962.40	100.00

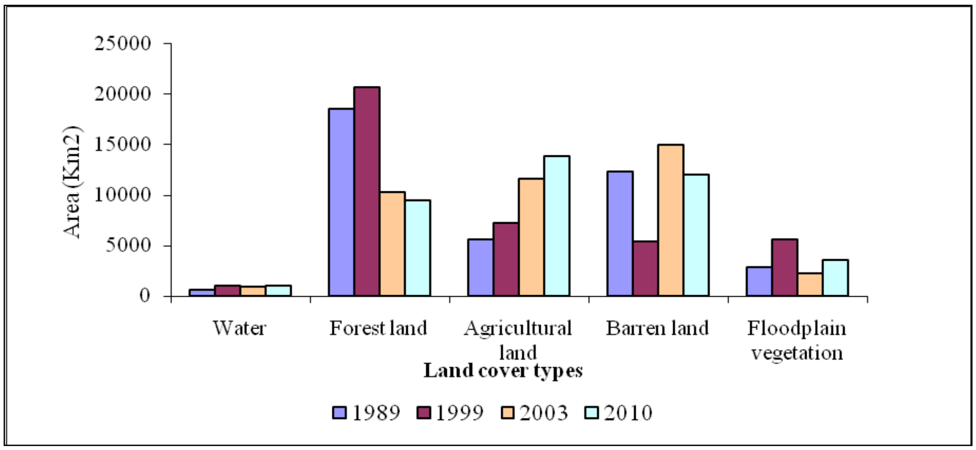


Figure 5.14 Land cover classification changes in the Lower Irrawaddy basin

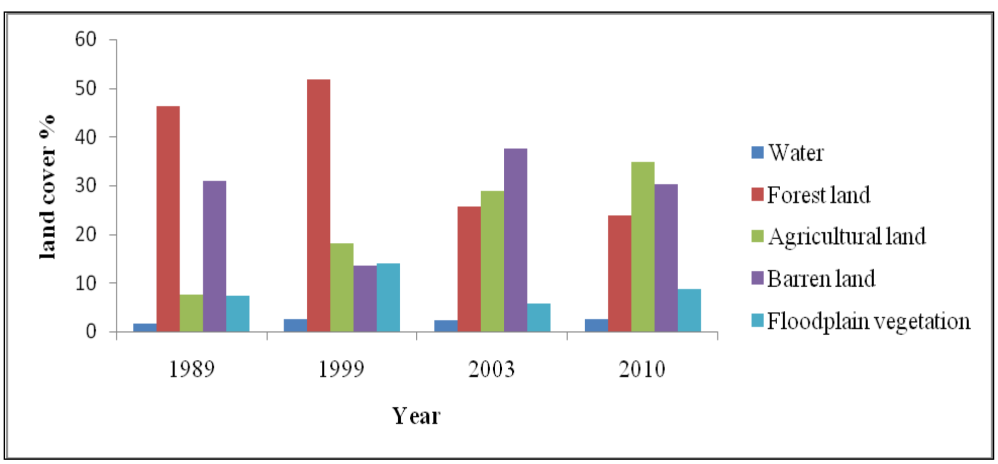


Figure 5.15 Land cover changes in the Lower Irrawaddy basin

Table 5.10 Land cover changes in the Lower Irrawaddy basin (1989-2010)

	1989		2010		Change	
Land use/cover	(Km^2)	(%)	(Km^2)	(%)	(Km^2)	(%)
Water	628.6	1.57	1009.1	2.53	+ 380.5	+ 0.96
Forest land	18515.02	46.33	9483.9	23.73	- 9031.12	- 22.6
Agricultural land	5554.31	13.9	13892.8	34.76	+ 8338.49	+ 20.86
Barren land	12369.15	30.95	12053.9	30.16	- 315.25	- 0.79
Floodplain vegetation	2895.32	7.25	3522.7	8.82	+ 627.38	+ 1.57
Total	39962.4	100	39962.4	100		

Land use/cover changes in the Lower Irrawaddy basin (1989 to 2010)

The post-classification comparison approach was employed for change detection of land use/cover changes, by comparing independently produced classified land use/cover maps. The main advantage of this method is its capability to provide descriptive information on the nature of changes that occurs. The change statistics are summarized in Table 5.10. The spatial distributions of each of the classes were extracted from each of the land use/cover maps by means of GIS functions. From these results, forest land covered 18515km^2 in 1989 and decreased to 9484km^2 in 2010. This represents a decrease in forest cover of 9031km^2 in 21 years, a 48.8% decrease or an average deforestation rate of 2.3% per year. The agricultural lands occupied 5554 km^2 in 1989 and increased to 13893 km^2 in 2010 which is a gain of 8338km^2 or 150.1%. Barren lands, consisting of mixed sand dune and shrub land decreased from 12369.15 km^2 in 1989 to 12053.90 km^2 in 2010. Floodplain vegetation land on the other hand has slightly increased from 2895.32 km^2 in 1989 to 3522.70 km^2 in year 2010. Presumably this is just because the conditions were wetter at the time the 2010 scene was acquired. Table 5.10 indicates that between 1989 and 2010 the amount of forest land decreased from 46.33% to 23.73% of the total area, while agricultural land, floodplain vegetation and surface water increased from 13.90% to 34.76%, 7.25% to 8.28% and 1.57% to 2.53% respectively. Barren land was slightly decreased from 30.95% to 30.16 %. The overall accuracy of land cover change maps, generated from post-classification change detection methods and evaluated using several approaches, reached 80 %.

Land use change and conversions between 1989 and 2010

Table 5.11 shows the land use change matrix in the classification of image pixel changes from 1989 to 2010. In pixel change matrix, the column represents how many of the pixels in the original year have been converted to other types in the final year. The row represents each pixel in their original value from each year. Table 5.12 shows the land use change matrix (Percentage) in the classification of image (Percentage) changes from 1989 to 2010. Table 5.13 shows the land use change matrix (km^2) in the classification of image (km^2) changes from 1989 to 2010. In the conversion matrix, the column represents how much of specific land use in the original years has been converted to other types by the final year. The row represents much of specific land use classification in their original from other types in the original year.

Table 5.11 Land use change matrix image (pixel) counts (1989 to 2010)

Class	Equivalent Class Pairings	
	1989	**2010**
Water	Water 6234 points <==>	Water 3804 points
Forest land	Forest land 12418 points <==>	Forest land 6455 points
Agricultural land	Agricultural land 1668 points <==>	Agricultural land 3630 points
Barren land	Barren land 4945 points <==>	Barren land 9122 points
Floodplain vegetation	Floodplain vegetation 1894 points <==>	Floodplain vegetation 3945 points

(2010) Pixel Counts	**(1989) Water**	**Forest land**	**Agricultural land**	**Barren land**	**Floodplain vegetation**
Water	389815	181369	220337	331188	104287
Forest land	24718	9935066	81399	821553	375498
Agricultural land	31739	3344782	4492742	7874239	1182762
Barren land	228337	8216136	1169127	4072935	990898
Floodplain vegetation	93431	818046	734444	1639551	952483
Class Total	768040	22495399	6698049	14739466	3605928
Class Changes	378225	12560334	2205307	10666531	2653445
Image Difference	472829	-11069886	10311347	-3764	709956

Table 5.12 Land use change matrix (percentage) (1989 to 2010)

(2010) Percentage (%)	**(1989)Water**	**Forest land**	**Agricultural land**	**Barren land**	**Floodplain vegetation**
Water	51	1	3	2	3
Forest land	3	44	1	6	10
Agricultural land	4	15	67	53	33
Barren land	30	36	17	28	27
Floodplain vegetations	12	4	11	11	26
Class Total	**100**	**100**	**100**	**100**	**100**
Class Changes	49	56	33	72.128	73.404
Image Difference	61	-49	153	-0.025	19.64

Table 5.13 Land use change matrix (km^2) (1989 to 2010)

(2010) Class (Km^2)	**(1989)Water**	**Forest land**	**Agricultural land**	**Barren land**	**Floodplain vegetation**
Water	316.63	147.32	178.97	269.01	84.71
Forest land	20.08	8069.76	66.12	667.31	305.00
Agricultural land	25.78	2716.80	3649.23	6395.85	960.70
Barren land	185.47	6673.56	949.62	3308.24	804.86
Floodplain vegetation	75.89	664.46	596.55	1331.73	773.65
Class Total	**623.84**	**18271.89**	**5440.49**	**11972.13**	**2928.92**
Class Changes	307.21	10202.13	1791.26	8663.89	2155.26
Image Difference	384.06	0.00	8375.39	36.59	576.66

Discussion and Conclusion

Land use in the study area is very dynamic in each classification type. Remote sensing technology has been a helpful way to monitor activities and conditions at the Earth's surface. This research presents the use of remote sensing and geographic information systems for monitoring land use and land cover of Lower Irrawaddy basin using the images taken from the United States Geological Survey. The information provided in this report is a valuable tool in the development of priorities for the management of the study area. Land Use classification map reflects the character of society interaction between men with its physical environment. LUCC time series of the lower Irrawaddy catchment in 1989, 1999, 2003 and 2010 are analyzed with satellite images and documents. The dominant land cover types are forest and barren land represent of approximately 50% of the total basin land. However, some of changes may not have occurred on the ground. These may be errors of classification and digital classification. This research work demonstrates the ability of GIS and Remote Sensing in capturing spatial-temporal data.

An attempt was made to capture as accurately as possible five land use land cover classes as they change through time. Except for the inability to accurately map out urban land use in 2010 due to the limitation, the five classes were distinctly produced for each study year but with more emphasis on built-up land as it is a combination of anthropogenic activities that make up this class; and indeed, it is one that affects the other classes. However, the result of the work shows a rapid growth in agricultural land between 1999 and 2003, while, the barren land increased between 1989 and 2010. It may be including settlement area. The significant output of this study was the development of a basin land cover classification map. Satellite imagery and classification data provided important information about the natural phenomena and socio economic data of the study area. The detailed ground truth survey data were necessary for assessing image analysis. It helped to increase the classification accuracy.

Detection of Land use/cover change from 1989 to 2010 in Lower Irrawaddy basin was based on RS/GIS analysis. There was significant change in land cover from 1989 between 2010, where most of the change occurred in Forest land cover and followed by agricultural land cover. All supervised classifications, Maximum Likelihood were tested to determine the best result based on the spectral response for each image. Therefore, all of the land use/ covers classification types are dramatically changed in Lower Irrawaddy basin. Monitoring land use/cover changes is necessary for guiding decision making for resource management. This study analyzed land use/cover changes between 1989 and 2010 and used the findings to produce the changes results. To achieve this, multispectral Landsat images for 1989, 1999 and 2003 and 2010 were used in a classification analysis with GIS. In particular, decline of forest and other natural vegetation covers, and the problem of agricultural land were noted as serious issues. This pattern shows the influence of human activity and environmental impact. However, this study only used satellite data which is probably limited and not sufficient to grasp the land use/cover change process in all its complexity. The information obtained however, is very useful for planning purposes and for the appropriate allocation of resources and demonstrate the potential of multi-temporal Landsat data to provide a precise and inexpensive means to analyze and map changes in land use/cover over time that can be used as inputs to policy decisions and land management. Therefore, the changes of land cover classified using remote sensing and GIS technologies provide observations which may show critical and undesirable environment impacts in Lower Irrawaddy basin.

6. MODELLING SOIL EROSION IN LOWER IRRAWADDY BASIN

6.1 Introduction

Research on soil erosion has a long scientific history and the underlying fundamentals of erosion processes have been investigated for many decades. But research is still ongoing and increasingly focuses on very detailed investigations of soil erosion processes and in particular on physically based modeling. Soil erosion is defined as the process of detachment and transportation of soil materials by erosive agents (Foster and Meyer, 1972). The main factors influencing soil erosion include climate factors of rainfall and wind, landscape relief, soil and bedrock properties, vegetation cover, and human activity (Foster 1982). Human activities can accelerate soil erosion in many ways, including agricultural practices and tillage, road and building construction, forest logging, urban development, mining, and grazing (Sundborg, 1982). Soil erosion is a natural process, but it can be accelerated by certain human activities. The soil loss quantity can be calculated as a product of the active hydrologic and topographic factors and reactive factors of erodibility, land use and land cover (Hahn et al., 1994). The complex process of erosion starts by the impact of raindrop or surface runoff. A portion of detached particles are carried down slope by flow in a process known as sediment transport.

The objective of this chapter is to explore the implementation of the Thornes erosion model in the Lower Irrawaddy River basins and to evaluate its ability to predict potential erosion rates in a large mountainous drainage basin setting. Erosion and sediment yield modeling approaches vary in terms of simulated processes, spatial and temporal detail, and data requirements. In this study, erosion is calculated using the Thornes soil erosion model which is a function of slope, soil erodibility, surface runoff volume and vegetation cover. This study is considering soil erosion and sediment supply to the river network from the Lower Irrawaddy catchment slopes to the Irrawaddy River. The study of sediment associated environmental problems is important and especially temporal and spatial scale of sediment dynamics in catchments and large river basins. Future study needs to examine sediment dynamics in the Upper Irrawaddy basin of soil erosion, sediment sources, rates and deposition, especially since the majority of the sediment yield of the Irrawaddy is derived from the upper catchment. However, given the time limitations for the current work, attention has been focused on the implications of land use change in the Lower Irrawaddy on soil erosion and potential sediment delivery to the river. Understanding the sediment delivery process at the drainage basin scale remains a challenge in erosion and sedimentation delivery research in Myanmar. Therefore, this spatially distributed erosion and sediment delivery will help to predict a part of the sediment dynamics in the Irrawaddy basin.

6. 2 Material and Methods

The development of a basin hydrological model uses spatial data to represent variations in the runoff generating processes across the study area. The significant variables include information on the basin's climate (e.g. maps of monthly precipitation, temperature, and hydrological data) and the hydrological response to catchments, such as land use map, geology, soil and topography. Geographic Information Systems (GIS) enables the spatial distribution of hydrological variables to be re[resented and is ideal for erosion and hydrology modelling.

In addition to the spatial data for time series, data from available satellite imageries and global data sources were required for defining the hydrological model and validating output. A summary of the spatial data used as input to the Thornes Soil Erosion model is given in Table 6.1 and the spatial data described, These data were obtained from various sources. Lower Irrawaddy basin DEM has a drainage basin area of 39416 km^2 and includes twelve basins (Figure 6.1 and Table 6.2).

Table 6.1 Required Inputs data for the basin hydrological model

Data type	**Description**	**Derivation**
Precipitation Rain-days Temperature	21 years daily rainfall values for 1985-2005 Average mean	Derived from Meteorology Department, Myanmar
Potential soil type	Majority value dominant of 5 type soil classification	Derived from FAO Digital Soil Map of the World
Land Cover	1989,1999,2003,2010	Landsat TM/ETM, USGS
Forest cover	NDVI	Satellite images
Minimum cell elevation Maximum cell elevation	Minimum, maximum and mean elevation of 1 km cells (1000 meters)cell size	Derived from the USGS's 1km×1km HYDRO1k DEM

Table 6.2 Lower Irrawaddy basin area and Sub-basin area (km^2)

Sub-basin	Area (km^2)
1	351
2	588
3	1002
4	1281
5	1852
6	2724
7	4087
8	4432
9	4725
10	4756
11	6172
12	7446
Total	39416

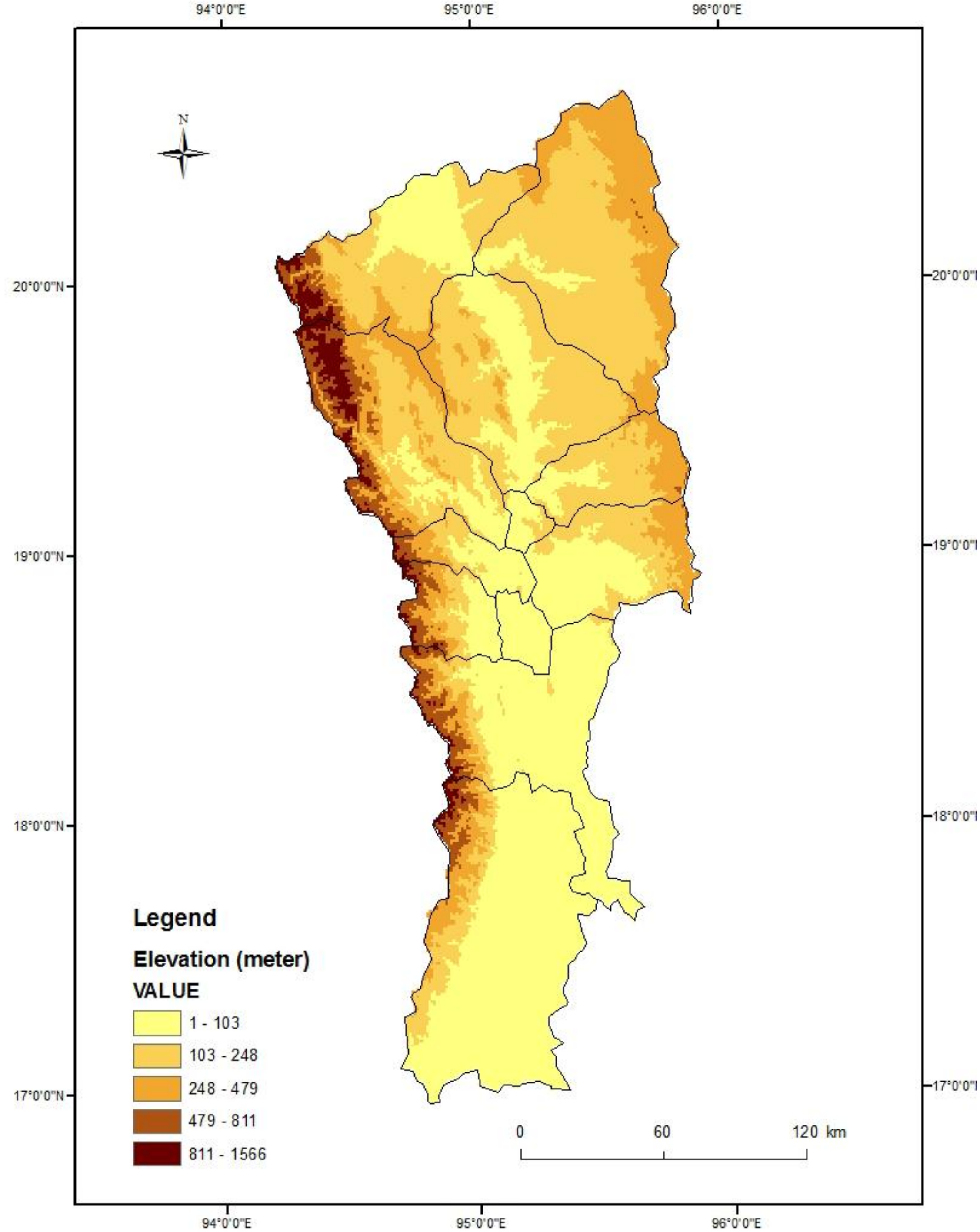


Figure 6.1 Map of the Lower Irrawaddy basin and sub-basins

6.3 Data development and processing

Soil Erosion modelling (Thornes Model)

Erosion is calculated as a function of the indicators of driving forces (e.g., runoff rate and gradient) and resistance to erosion (e.g., soil properties and vegetation cover). Thornes (1985, 1990) developed a conceptual erosion model that contains a hydrological component based on a runoff storage type analogy, a sediment transport component and a vegetation cover component. This modelling approach has been used in various scales study of predicting erosion (Zhang et al., 2002, Saaverdra 2005, Anh Luu 2009, Ali, and De Boer 2010). This study outlines the implementation of soil erosion model followed by Aliand De Boer (2010) who used the procedure to estimate the spatial distribution of erosion rates across the Upper Indus basin (Pakistan). They then coupled the erosion model to a sediment delivery model to predict sediment yield variability. In the current study time and data limitations have constrained the study to developing the erosion map as a demonstration of how spatial variations of erosion rate could be assessed in a region with limited data. There are some significant uncertainties about the quality of input data for the modeling procedure.

The Thornes erosion model requires estimates of the rate of surface runoff production and based on square grid cells, and starts with the assumption that daily precipitation can be approximated by an exponential frequency distribution within a specified area (Thornes, 1990). The modelling framework presented in this study is based on physiographic characteristics of the basin, and hence it can be used for the estimation of sediment yield in other ungauged drainage basins which have similar hydro-meteorological, topographical and land use conditions.

The Thornes erosion model is selected for this study because:

1. It has low data requirements compared to other models;
2. The required data are realtively easy to obtain and;
3. It has the flexibility of model application on multi-temporal and spatial scales.

Thornes (1985, 1989) established a physical-based soil erosion model by combining sediment transport and vegetation protection in the following equation:

$$E= KQ^{m} S^{n} e^{-bVc} \qquad \text{(Equation 6.1)}$$

Where E = erosion (mm/day or mm/month depending on the time step);

k = soil erodibility coefficient calculated from soil grain size;

Q = overland flow (mm per time step) derived from sub-models of varying complexity;

S= slope (% or m/m);

VC = vegetation cover (%);

m, n, b = constants, where m = 2, n = 0.167 and b = 0.07

6.4 Watershed delineation for Arc-Hydrology functionality

Digital Elevation Model

This section explains the required inputs for the selected data and soil erosion and available global data sources. For investigating the path of surface water over the topography of the land surface, watershed boundaries can be delineated from a digital elevation model (DEM) by using GIS software. The study uses from U.S. Geological Survey's (USGS) HYDRO1k DEM for South East Asia, adjusts it where errors are perceived, and derives a vector map of river basins and their sub-basins named after the largest tributary within its limits. The documentation provided can be used as a basin hydrology for requiring the use of ENVI 4.7 and ArcGIS version 10, with Spatial Analyst of Hydrology Tools. The delineation of the basin required the acquisition of topographical, sub-basin and hydrological datasets. Topographic data and parameters required for water balance and erosion modeling include parameters that describe the geometry of elevation surface and flow over terrain surface such as slope, flow direction; flow accumulations and all are determined by DEM. These datasets have to use for erosion model calculation outline in the following segments of study basin. The HYDRO1k DEM was developed from the USGS 30 arc-second DEM (GTOPO30) of the world and adjusted to remove possible effects interfering with correct movement of water across land surface. The study area of the Lower Irrawaddy basin DEM was downloaded from Hydro 1k datasets for Asia .This was completed by identifying and filling natural sink features, and verifying the elevation model. The resulting DEM determined flow direction, flow accumulation and slope grids as well as vector streamlines and sub-basin boundaries. The dataset was selected because it is freely available and is a standard geo-referenced dataset and has a resolution of 1km. The hydrological corrected for calculation of derived parameters such as flow direction and slope image from DEM. This data is used as input to quantify the characteristics of the land surface. The Myanmar Management Unit (MIMU, Source website: http://themimu.info) allows users to search for specific maps of State division or townships maps and provides information on environmental, health, disasters and socio-economic supporting country-wide of Myanmar's GIS shape files. The MIMU is governed by a Steering Committee which represents the interests of the Humanitarian Country Team (HCT) membership and it reports to the United Nations Resident (UN-RC) and Humanitarian Coordinator (HC). This study used Myanmar state and division boundary and river network shape files from MIMU.

6.4.1 Creating Watershed delineate for Lower Irrawaddy basin

All datasets and required input maps for the selected model have to be created with the same projection, co-ordinates and geo-references with resolution as close as possible to the 1*1km^2 and high resolution of the satellite images. For this study, a coordinate system with UTM 1984 projection encompassing the study area and appropriate for input maps from different co-ordinate system projection to standard working co-ordinates system of WGS_1984_UTM_ZONE_46N was used. The spatial resolution of 1km was selected for the lower Irrawaddy basin and the cell size of 1000 meter was created under working coordinate system to be used for the extract watershed map is delineated. Watershed and sub basins (sizes) are estimated from DEM 1 cell =1 km^2 and flow accumulation line from Hydro1k DEM. This spatial scale is enough to explain spatial pattern and distribution of water resources and soil erosion at the large basin scale. The tools (Software) used in this study include, ENVI 4.7, ArcGIS 10, Spatial Analysis Tools of Hydrology and Microsoft Excel spreadsheet.

6.4.2 Global data sets preparation and basin hydrology analysis

The following steps were used to create watershed boundaries from digital datasets and analyze stream network and land cover characteristics within the boundaries. The processes are watershed delineation using a paper map and GIS in a multiple steps process **(**Table 6.3).

Table 6.3 watershed delineation for Arc hydrology functionality

Processing function	Creation with images and datasets
1. Setup the ArcGIS working environment	Extracting data and images, geo-processing
2. Creating a basin DEM	Start with digital elevation model, hydrology tools
3. Creating a Flow direction	Fill sinks grid original DEM grid
4. Creating Flow Accumulation	Flow direction grid fill sinks grid
5. Creating Stream network	Flow Accumulation grid and Flow direction grid
6.Creating Watershed Pour Points	Stream definition grid and catchment grid
7.Delinate watersheds	Stream layer map to create Poly points (outlet)
8.Analyze watershed Stream network	Watershed polygon shape file, Hydro tools
9.Analyze watershed Elevation data	Watershed polygon shape file, Hydro tools
10. Export Watershed Map	

6.4.3 Analysis of Watershed stream network

Geographic Information Systems (GIS) and RS support the hydrologic model with adequate spatial information from the layers and database. The availability of data in digital form allowed the proposed method to make the best possible usage of existing hydrological information. Attribute layers such as land cover, elevation, precipitation and hydrologic soil groups are important to distinguish between data models. Topographic map features are helpful for watershed delineation. **Figure 6.2** shows the illustration of GIS data layers organized into separated themes for soil erosion modelling.

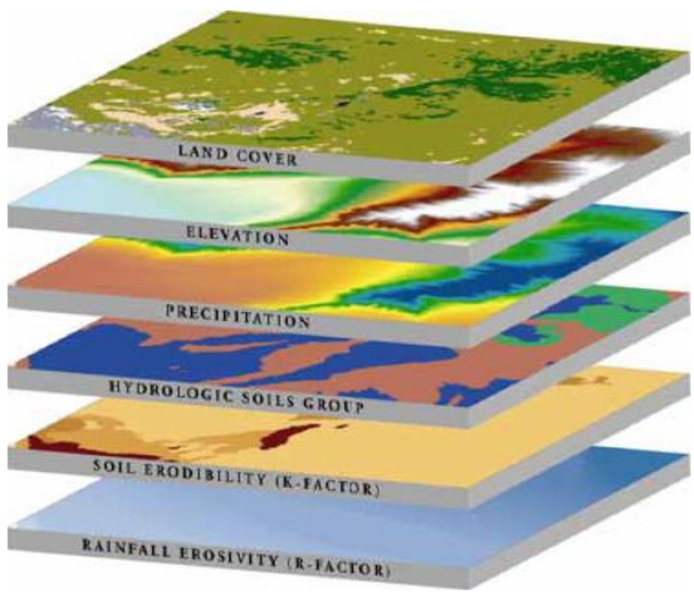


Figure 6.2 Illustration of GIS data layers organized into separate themes

The contour lines and Digital Elevation Model (DEM) allow one to imagine the direction of flow of runoff over the land. The surface runoff flow can be determined by using contour lines of elevation on a topographic map. Watershed boundary delineations are useful for watershed hydrology. Knowing watershed boundaries would allow determining what land uses, human activities and possible sources of water and associated problems are contained within the watershed or outside. The delineation of a watershed can determine its size using different methods. In other cases, scientists might want to show a watershed delineated on a map for a scientific article, environmental report, or research display. There are a number of things to produce when determining the direction of flow. Using the gridded Hydro1k Digital Elevation Model (DEM) of Lower Irrawaddy basin a map is created and tested for smoothing filling sinks with ArcGIS spatial analysis tool. Figure 6.3 is after filled DEM of the Lower Irrawaddy basin.

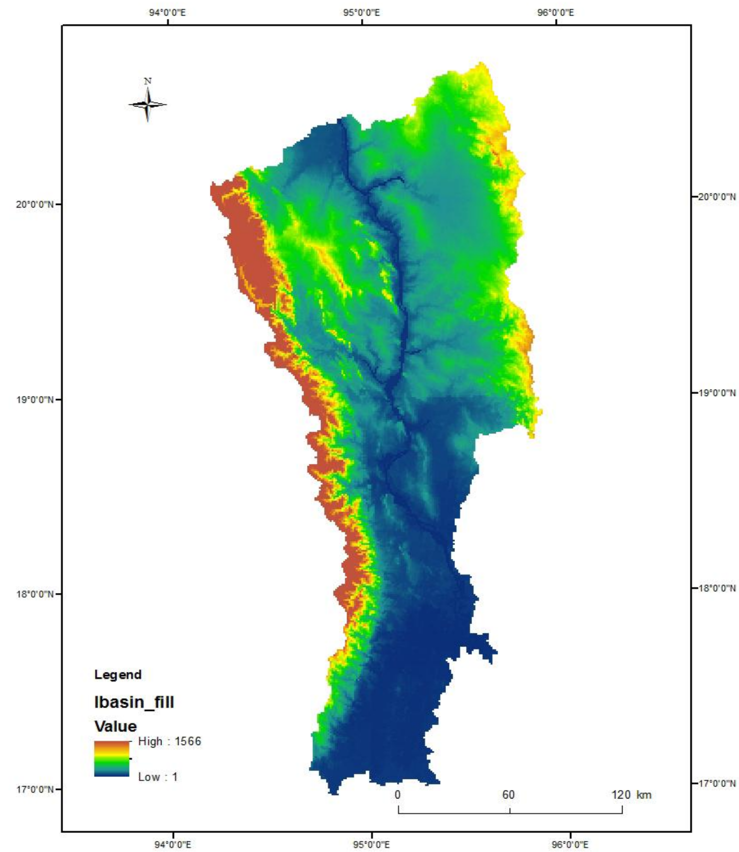


Figure 6.3 Lower Irrawaddy basin filled DEM

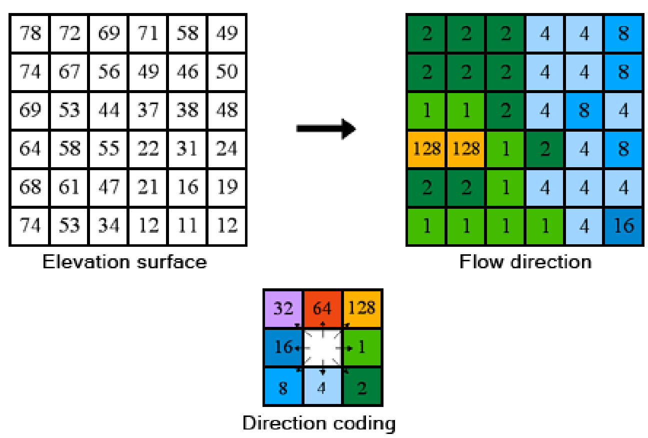


Figure 6.4 Illustration of flow direction grid cell convection

The direction of flow is determined by finding the direction of steepest descent, or maximum drop, from each cell. Figure 6.4 illustrated the flow direction grid cell convection and Figure 6.5 shows the flow direction map of the lower Irrawaddy basin.

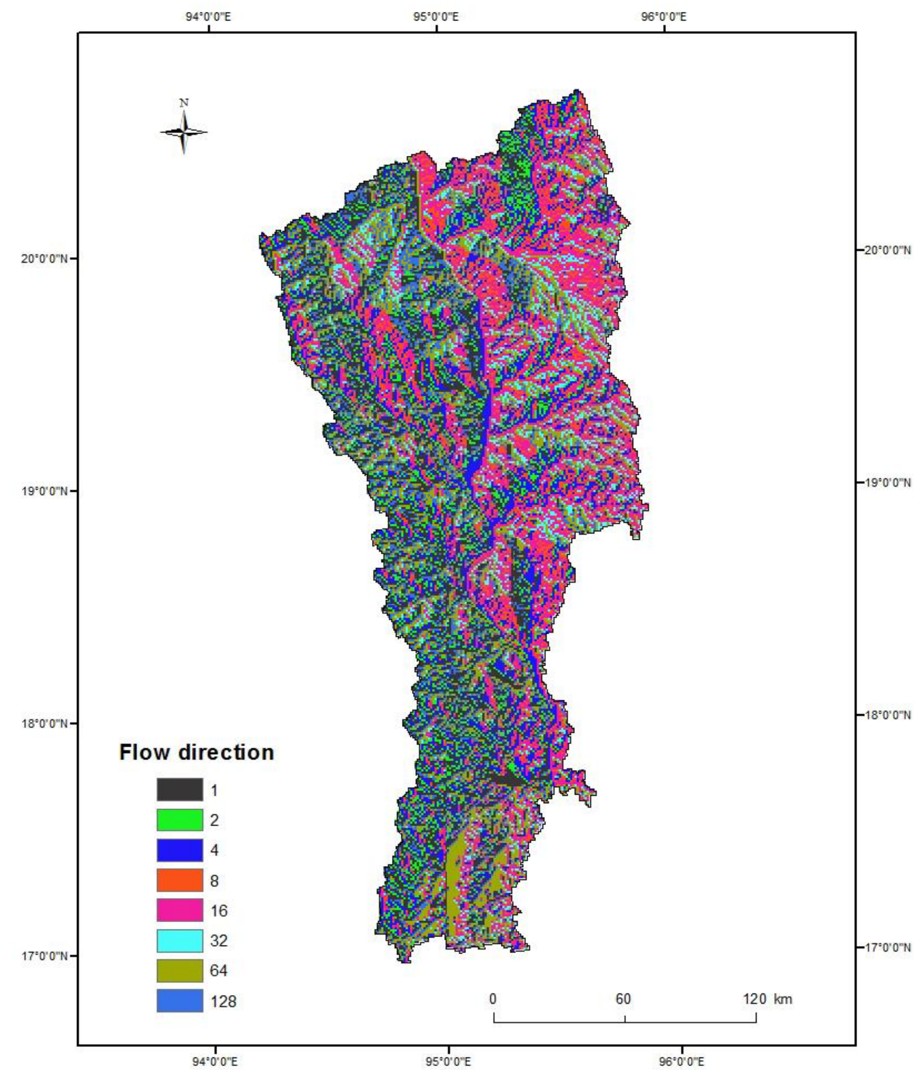


Figure 6.5 Flow direction of The Lower Irrawaddy basin

Determination of the flow direction from the DEM is the first step in delineating the watershed boundary**.** The next steps in hydrological model to define the flow accumulation and it used to generate a drainage network based on the direction of each flow cell. The flow accumulation data layer is defined as the amount of upstream area draining to each cell and its result shows the upstream catchment area. Hydro1k DEM grid cell size is 1km resolution and the flow accumulation values can convert directly into drainage area in square kilometres with value from 0 at high topographic cell of lower Irrawaddy basin**.** Figure 6.6 illustrates the result output image for created a stream network, using the Flow Accumulation tool to calculate the number of upslope cells flowing to a location and outlet pour point.

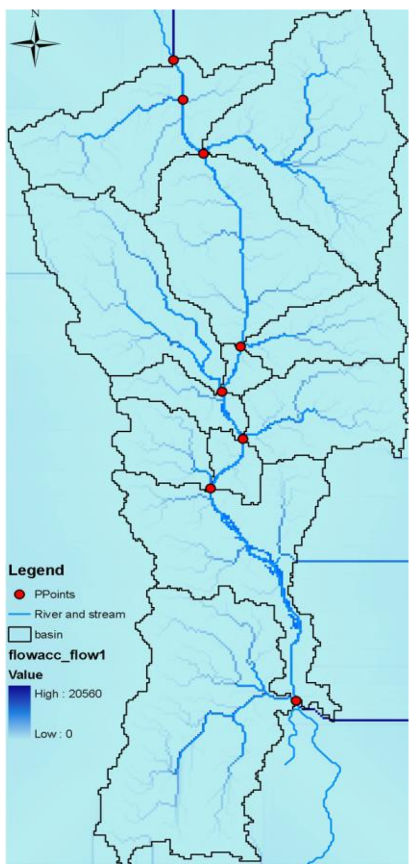


Figure 6.6 Stream flow accumulation and outlet pour point

6.4.4 Export of Watershed Layout Map

The final step is to run the watershed function in ArcGIS to automatically delineate the watershed boundary (Figure 6.7). The watershed boundary is delineated from the original DEM, the output data file can be used as a template to cut out, or extract, the exact area from other digital maps. The delineated Lower Irrawaddy basin DEM serves as the base template for the Thornes Model calculations.

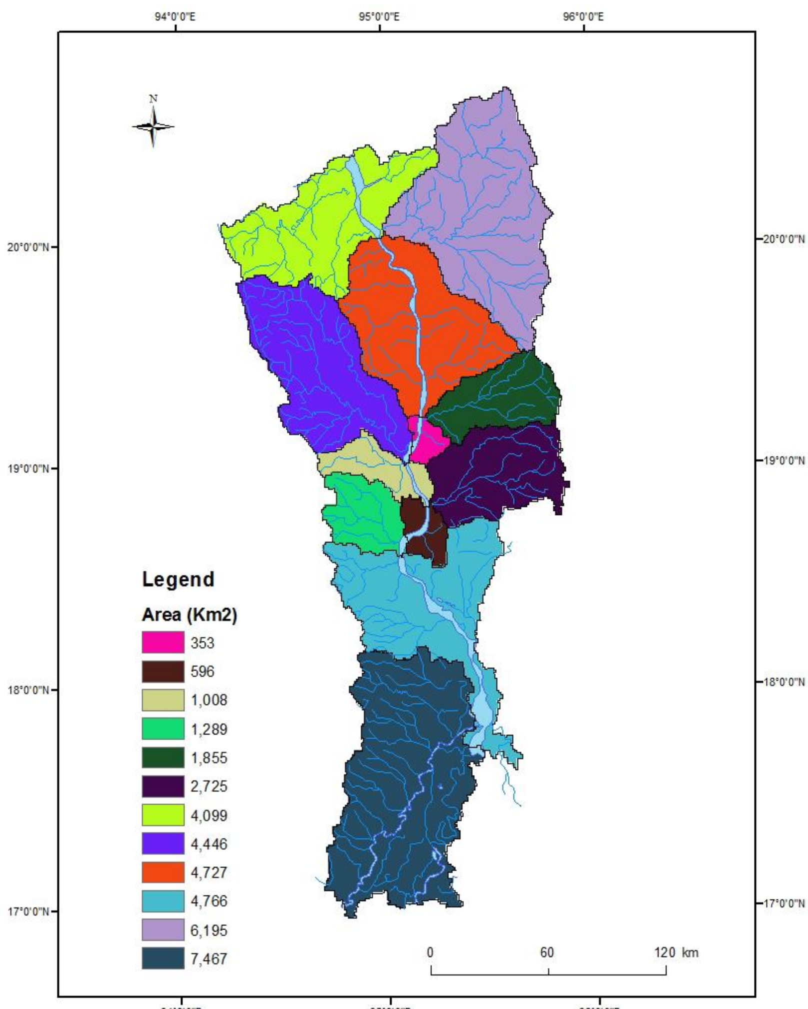


Figure 6.7 Watershed layout Map of the Lower Irrawaddy basin

6.5 Soil data and soil erodibility factor

Soil data are required to estimate soil water holding capacity for different crops and to estimate soil erodibility by soil texture class for estimating erosion and runoff. Soil data are usually derived from thematic maps and global digital soil database, but high accuracy simulation models may require field measurements of soil properties. In this study, information about soil profile characteristics is derived from the FAO Global soil database. The soil erodibility factor (k) is a quantitative description of the inherent erodibility of a particular soil based on a measure of the soil particles susceptibility to detachment and transport by rainfall and runoff. Hydrological processes such as infiltration, total water capacity and rain splash are influenced by soil texture as reflected in the erodibility factor. There is no detailed soil map for the study area. Soil mapping units were updated from FAO soil units of soil types. Soil groups are the Yellow brown forest (Acrisol ferric), Alluvial soils (Fluvisol), Turfy primate soil (Gleysol), Meadow Alluvial soil (Gleysol Fluvisol) and Meadow swampy (Humic Gleysol). The results of soil classification and texture were generalized from FAO soil maps and data sets. However, producing a soil map for analysis of basin scale hydrologic modeling and simulated runoff is quite difficult because of the scale of the FAO data. Figure 6.8 illustrates the soil types of the Lower Irrawaddy basin. The lower part of the basin is dominated by swampy and gley soils, while the topography controls the soil distribution to some extent. The procedure for assigning an erodibility value to a soil texture class is illustrated in Section 6.7.2.

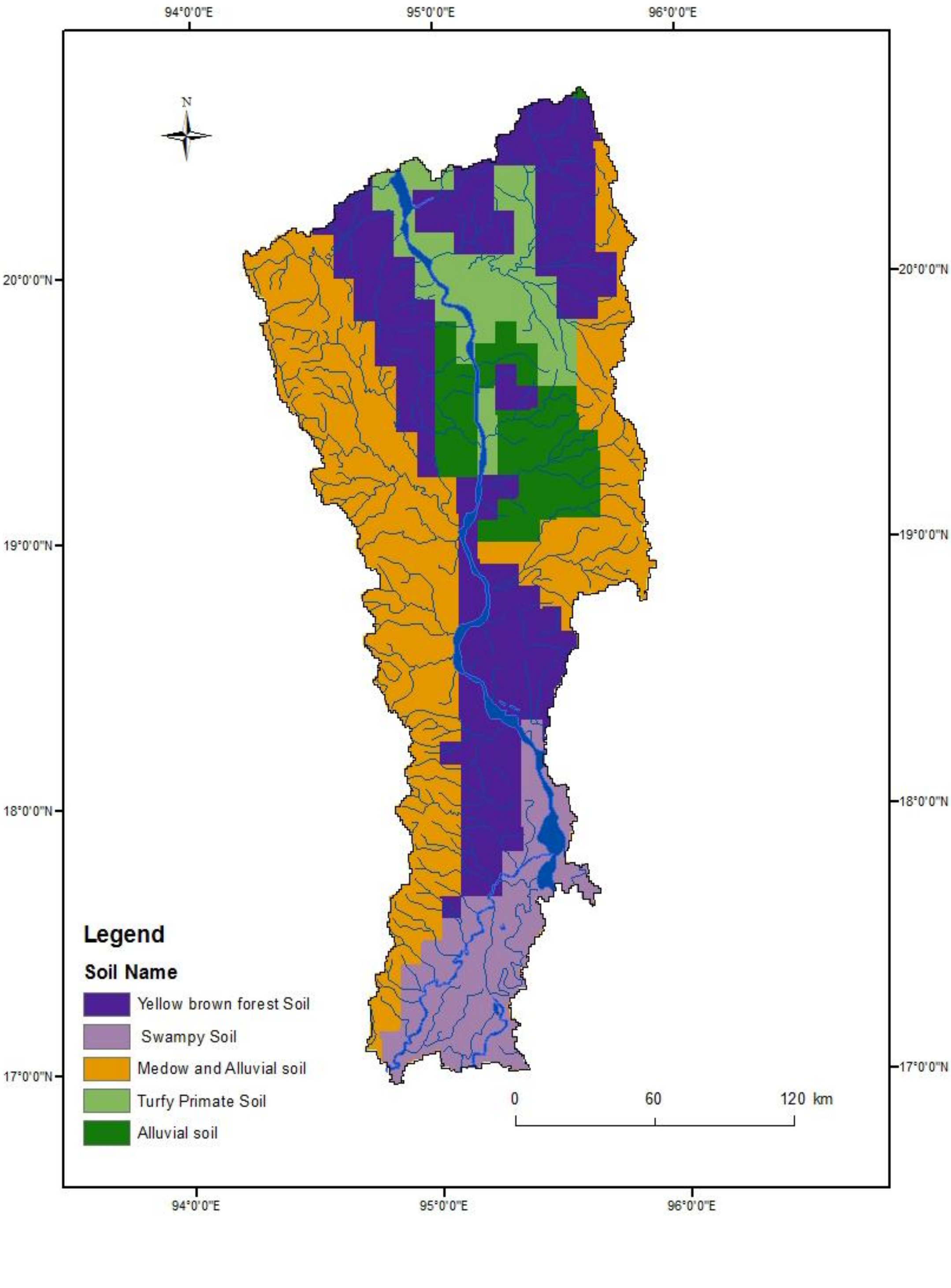


Figure 6.8 Soil Map of the Lower Irrawaddy basin

6.6. Topography and Slope Data

Figure 6.9 shows the slope map of the Lower Irrawaddy basin. Slope data layers that shows the elevations between each cell and its neighbors cells available from Hydro1k decimal degree. For the slope fraction by radius for the Thornes soil erosion model calculation is used by this calculation formula. Slope gradient = tan θ where θ is slope angle (degrees) as calculated in GIS. The study area slope value found in maximum to minimum value range is 0 to 22 degrees.

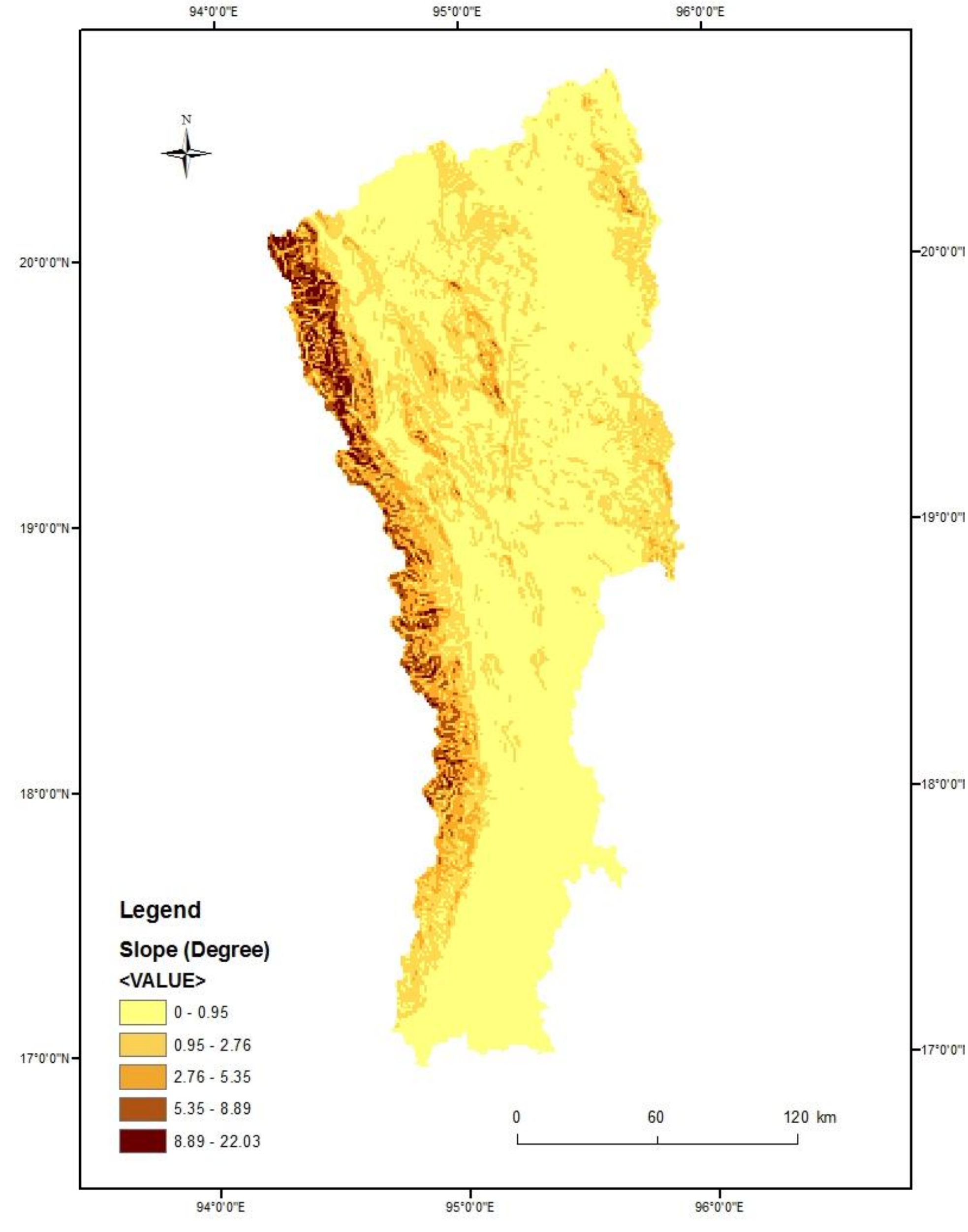


Figure 6.9 Slope Map of the Lower Irrawaddy basin

6.7 Runoff estimation for Lower Irrawaddy basin

Overland flow is the main source of energy causing soil erosion. Because of the complex interaction among precipitation, evapotranspiration, infiltration and overland flow, a number of models have been developed for computing overland flow in a range of conditions. The rainfall data were obtained from Meteorology Department of Myanmar. Rainfall-runoff modelling is an important tool in the study of water resources and water management of the watersheds. In un-gauged or poorly gauged basins, the dependence on observed river discharge data for calibration restricts applications of rainfall-runoff models. A rainfall-runoff model can be really helpful in the case of calculating discharge from a basin.

The transformation of rainfall into runoff over a catchment is known to be very complex hydrological phenomenon, as this process is highly nonlinear, time-varying and spatially distributed. Over the years researchers have developed many models to simulate this process. Numerous methods and techniques are used in the hydrologic modeling for the estimation of the runoff. Each model uses specific parameters as inputs for the analysis of runoff. Rainfall-runoff models are mainly used for river flow forecasting for the management of the water and sediment sources. The problem most often encountered in hydrological studies is the need for estimating stream flow from a watershed for which there is some record of precipitation but no records of stream flow. An approach to solution of this problem is to compare runoff characteristics with those of watershed characteristics. Watershed characteristics which may be mostly readily used to estimate the volume of runoff that will result from a given amount of rainfall are soil type and land cover, which includes land use.

In the Lower Irrawaddy basin, availability of runoff records is very limited compared to rainfall records, especially for medium and small catchments. Many such methods are available ranging from simple empirical equations relating catchment characteristics to the runoff, to complicated physical models that flow the movement of water from the farthest point of the catchments. Hydrologists of the Soil Conservation Services constantly encountered the problem of estimating direct runoff where no records are available for the specific watershed. The United States Soil Conservation Service (USDA, 1985) curve number method is a well accepted tool in hydrology, which uses a land conditions factor called the curve number method. Its reliance on only one parameter and its responsiveness to four important catchment properties, i.e. soil type, land use, surface condition, and antecedent moisture condition, increased its popularity. The hydrological data in the Lower Irrawaddy basin study is limited. Therefore, to estimate the surface runoff for this watershed the US Soil Conservation Service Method (SCS) was applied. This paper presents the results of a basin scale rainfall- runoff study of the Lower Irrawaddy basin in Myanmar using the GIS and RS environment.

6.7.1 Watershed Boundary, Land Use and Soil Group

The watershed boundary was extracted from USGS Hydro1k and the grid to conduct the experiments of Lower Irrawaddy basin and sub-basins. The conventional land use/land cover map of the watershed was based on five Landsat images classification from 2010. Processing with ArcGIS 10 of Special Analysis Tools and the attribute tables were linked to calculate Microsoft Excel. The globally digital database of available Food and Agriculture Organizations (FAO) soils dataset for Myanmar was adopted to classify soils for different basin areas.

6.7.2 The SCS Curve Number Method

The SCS curve number method (SCS, 1972), also known as the Hydrologic Soil Cover Complex Method was developed by the Soil Conservation Service (SCS) of the US Department of Agriculture for use in rural areas. It is a versatile and widely used procedure for runoff estimation. The requirements for this method are low, rainfall amount and curve number. The curve number is based on the area's hydrologic soil group, land use treatment and hydrologic condition. As defined by SCS soil scientists, soils may be classified into four hydrologic groups (A, B, C and D), (USDA, 1985), depending on infiltration, soil classification and other criteria. Land use and treatment classes are used in the preparation of hydrological soil-cover complex, which in turn are used in estimating direct runoff. The main soil types are Meadow and meadow alluvial soil, yellow brown dry soil, Turfy prime soil, yellow brown forest soil, alluvial soil and

Gley and Gley swamp soil. To differentiate between soils with different permeability rates and textures, each soil is assigned to a Hydrologic Soil Group. Hydrologic soil groups range from A to D based on infiltration and texture. The erodibility factor is derived from the texture category provided by Stone and Hilborn (2000) Table 6.4. Table 6.5 shows the contributory factors in assigning a soil to a hydrologic soil group. Figure 6.10 illustrates the soil erodibility K factor map of the Lower Irrawaddy basin.

Table 6.4 Soil Erodibility Factors, after Stone and Hilborn (2000)

Texture Class	Organic Matter Content (%)		
	Average	Less Than 2%	More Than 2%
Clay	0.22	0.24	0.21
Clay loam	0.30	0.33	0.28
Coarse Sandy loam	0.07	0.00	0.07
Fine Sand	0.08	0.09	0.06
Fine Sandy loam	0.18	0.22	0.17
Heavy clay	0.17	0.19	0.15
Loam	0.30	0.34	0.26
Loamy fine sand	0.11	0.15	0.09
Loamy sand	0.04	0.05	0.04
Loamy very fine sand	0.39	0.44	0.25
Sand	0.02	0.03	0.01
Sandy clay loam	0.20	0.00	0.20
Sandy loam	0.13	0.14	0.12
Silt loam	0.38	0.41	0.37
Silty clay	0.26	0.27	0.26
Silty clay loam	0.32	0.35	0.30
Very fine sand	0.43	0.46	0.37
Very fine sandy loam	0.35	0.41	0.33

Table 6.5 Hydrologic Soil Group and Erodibility factor in Lower Irrawaddy basin

Solid ID	Soil Name	Sand % top Soil	Silt % top Soil	Clay % top Soil	Texture class	Erodibility factor
13	Swampy Soil	9.2	26.1	64.8	Clay	0.22
20	Gley & Swampy Soil	58.7	16.3	25	Sandy loam	0.13
31	Alluvial Soil	36.4	37.2	26.4	Loam	0.3
40	Yellow brown forest Soil	78.9	8.2	12.4	Loamy sand	0.04
42	Turfy primate Soil	6.9	30	63.1	Clay	0.22
43	Medow and alluvial Soil	55.2	21	23.8	Sandy loam	0.13

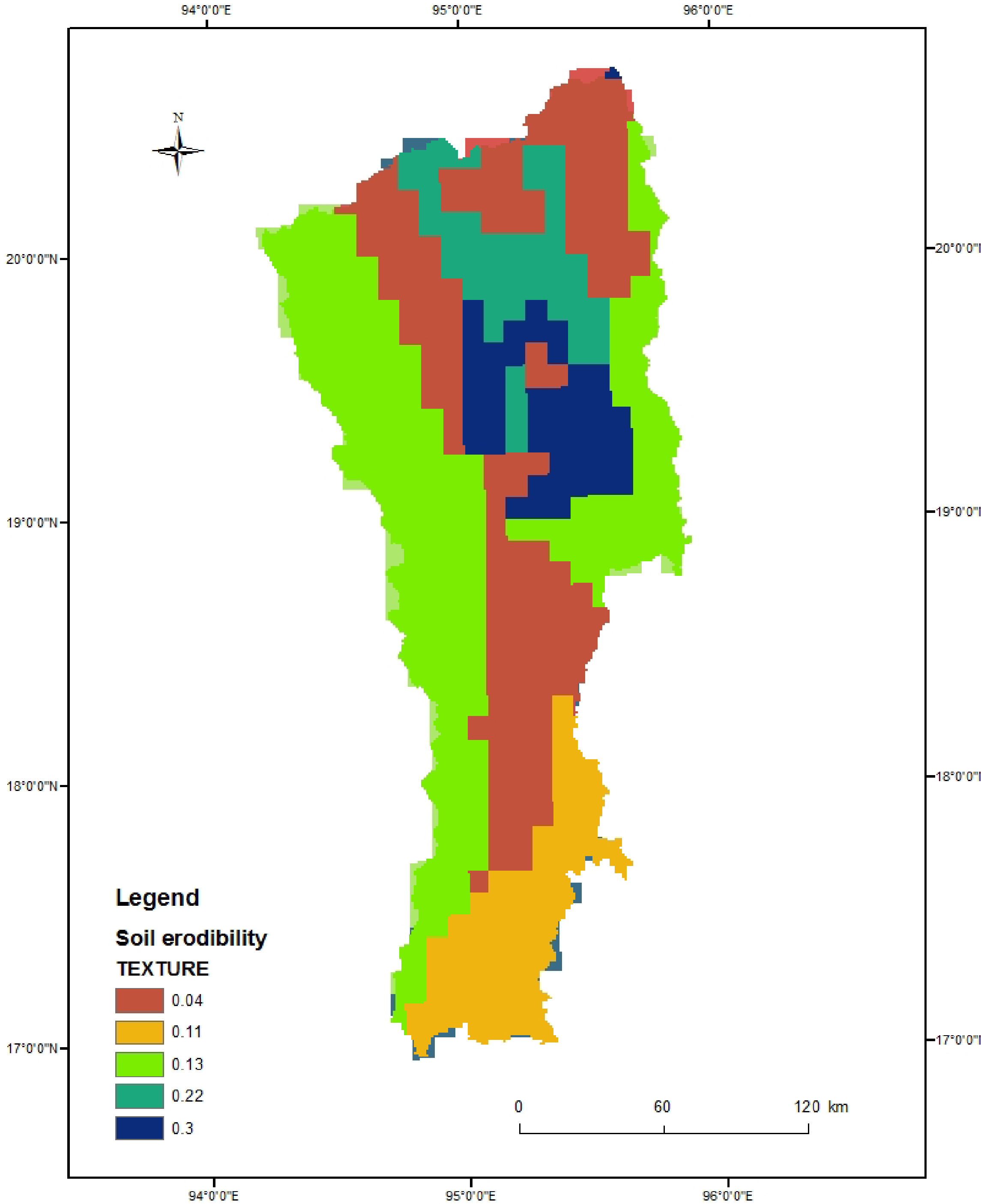


Figure 6.10 Soil erodibility (K) map of the Lower Irrawaddy basin

The important soil characteristics that influence the hydrological classification of soils are effective depth of soil, average clay content, infiltration characteristics and the permeability. Following is a brief description of the three hydrologic soil groups of B, C and D in study area**.** It is used to compute the direct runoff depending on the rainfall data and the watershed coefficient i.e. Curve Number (CN) as input parameters (Sharma and Singh, 1992; Nayak and Jaiswal, 2003). In the SCS-CN method data defines the basin properties, like rainfall data, soil conditions, and topographical condition (i.e. the vegetation available above the earth surface data). The SCS-CN method has been widely used to compute direct surface runoff. The SCS-CN method is based on the water balance equation and two fundamental hypotheses. The first hypothesis equates the ratio of the amount of direct surface runoff Q to the total rainfall P (or maximum potential surface to the runoff) with the ratio of the amount of infiltration to the amount of potential maximum retention S. The second hypothesis relates initial abstraction (Ia) and potential maximum retentions. Thus, the SCS-CN method consists of the following equations (Subramanya, 2008).

Equation 6.2: SCS-CN method formula.

$$Q = \frac{(P - Ia)2}{(P - Ia) + S}$$

where,
Q = runoff (mm)
P = rainfall (mm/24hr)
Ia = initial abstraction (mm)
S = potential maximum retention after runoff begins (mm)

The relation between Ia and S was developed by analyzing the rainfall and runoff data from experimental small watersheds and is expressed as Ia= 0.2S. Combining the water balance equation and proportional equality hypothesis, the SCS-CN method is represented as:

Equation 6.3: Potential maximum retention formula

$$Q = \frac{(P - 0.2S)2}{P + 0.8S} \qquad (\, P > 0.2S)$$

The potential maximum retention storage S of watershed is related to a CN, which is a function of land use, land treatments, soil type and antecedent moisture condition of watershed. The CN is dimensionless and its value varies from 0 to 100.The S-value in mm can be obtained from CN by using the relationship US Soil Conservation Services Model (Murth, 2004).

Equation 6.4: Storage (S) value formula

$$S = \frac{25400}{CN} - 254(mm)$$

Antecedent Moisture Condition (AMC) is an indicator of watershed wetness and availability of soil moisture storage prior to a storm, and can have a significant effect on runoff volume. Recognizing its significance, SCS developed a guide for adjusting CN according to AMC based on the total rainfall in the 5-day period preceding a storm. Three levels of AMC are used in the CN method: AMC-I for dry, AMC-II for normal, and AMC-III for wet conditions.

The following equations are used to calibrate the curve number for three conditions of dry, wet and normal conditions.

Equation 6.5: AMC I formula (for dry condition)

$$CN_I = \frac{4.2 \times CN_{II}}{10 - 0.058 \times CN_{II}}$$

Equation 6.6: AMC II formula (for normal condition)

$$CN_{II} = \frac{25400}{254 + S}$$

Equation 6.7: AMC III formula (for wet condition)

$$CN_{III} = \frac{23 \times CN_{II}}{10 + 0.13 \times CN_{II}}$$

In this study, daily runoff has been computed for AMC III using daily rainfall data of Pyay Station in 2002. The equation (6.5) was considered and applied to the highest rainfall experienced in Lower Irrawaddy basin. As a result of the calculations, based on the SCS method, it was found that the daily surface runoff rate of mean precipitation (P) 122 mm/ day (19 May 2002) .The classification of the lower Irrawaddy basin area of each land use types of dry, normal and wet moisture conditions are shown in Table 6.6.

Table 6.6 Classification of Antecedent Moisture Condition (AMC)

AMC	Condition	CN	Total Antecedent Rainfall(mm)	Total Rain days
I	Dry	77	161 mm	12 days, August 2002
II	Normal	89	248 mm	8 days, May 2002
III	Wet	94	352 mm	7 days, September 2002

Curve numbers for a range of Land cover categories that could be identified from land use/cover classification analysis from 1989 to 2010 were calculated. SCS curve number grid is used by many hydrologic models to extract the preparing form land use data for CN number grid (Table 6.7). Five classes to qualify the slope were introduced (Sprenger 1978) and curve number slope range is less than 1% is flat, 1-5 % is slightly sloping, 5-10 % is highly sloping, 10-20% is steep and greater than 20% is very steep condition. Figure 6.11 illustrates the land cover CN map of the Lower Irrawaddy basin.

Table 6.7 Land use/cover and CN number in Lower Irrawaddy basin

Land use	Soil group	Area(km^2)	CN	S	P	I_a	Q(mm/24 hrs)
Forest land	C	9483.9	77	75.87	161.00	15.17	95.291
Agricultural land	C	13892.8	85	44.82	112.00	8.96	71.800
Barren land	C	12053.9	90	28.22	248.00	5.64	84.051
Flood plain vegetation	D	3522.7	89	31.39	112.00	6.29	213.937

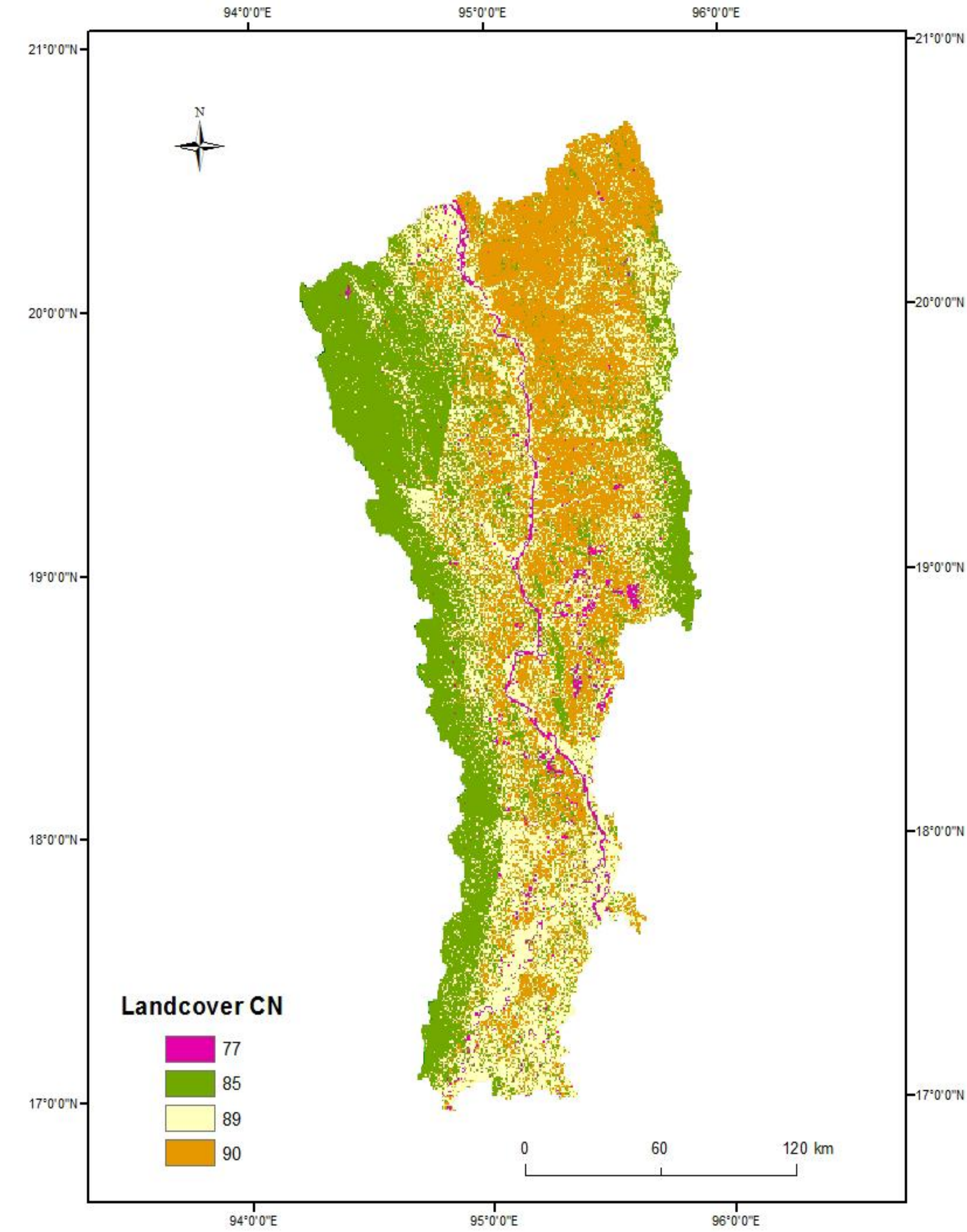


Figure 6.11 Land cover CN map of the lower Irrawaddy basin.

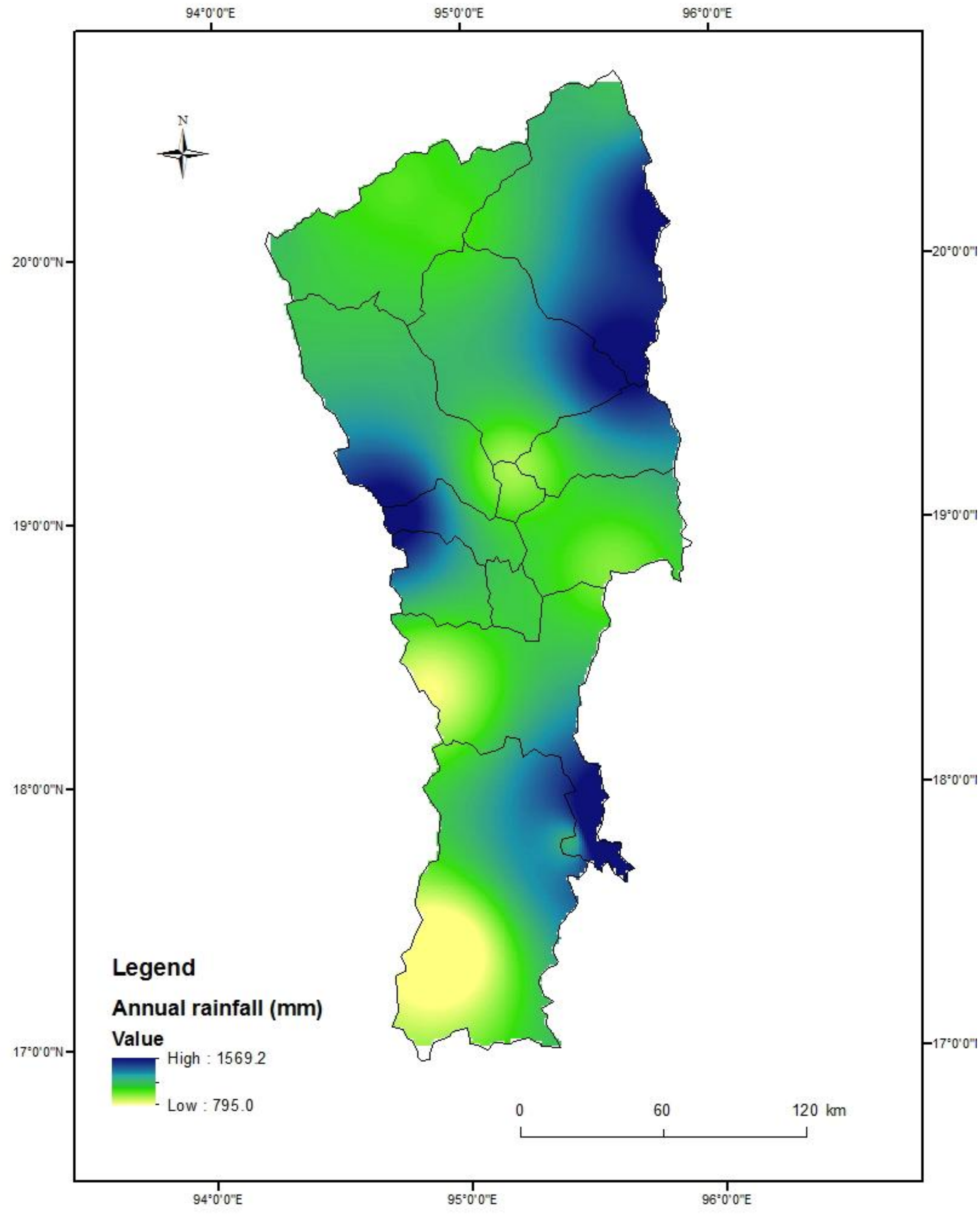


Figure 6.12 Rainfall Interpolation of (Inverse Distance Weighted Method)

Within the study area, rainfall varies spatially, temporally, and seasonally. Spatial interpolation is needed in hydrology, especially when modeling rainfall-runoff and flow forecasting are involved. Rainfall observations obtained by five of rain gauges (annual rainfall mm) within or close to the study area were used in a linearly weighted technique (Inverse Distance Weighted Method) (Figure 6.12) for the creation of an interpolated precipitation surface. The calculations and results, based on the SCS method, shows that the average annual runoff depth for year 2000 in Lower Irrawaddy basin**,** the total volume of water that can be collected is around 5319.54 m^3/s. The available rainfall data is from a sparse network which does not sufficiently represent the surface of Lower Irrawaddy basin. Figure 6.13 shows the runoff coefficient per grid cell distributions in the lower Irrawaddy basin. The procedure also generates thematic maps of runoff volume and average runoff depth for the sub-basins. The data from more rain gauges will give a more accurate interpolated precipitation surface. Geographical Information Systems (GIS) Hydrology Tools can be used for calculation the rainfall-runoff in Lower Irrawaddy basin. The model is automated, and requires the input of some parameters related to the rainfall, soil and land cover and the terrain DEM. The calculation is Spatial Analysis that can be used on SCS-CN method with the ArcGIS software. The Rainfall Runoff result can be used as a soil erosion tool for the predicted rainfall is used as an input. Furthermore, the implementation of the soil erosion model demands for rainfall runoff amounts can function as the starting point for design of soil and water conservation and evaluating the impact of alternate land use and basin management decisions.

The preceding investigation into SCS Curve Number demonstrates that the relative lack of data on soil types and the sparse network of precipitation data make the calculation of CN difficult. Nevertheless, the empirical procedure based on CN can be an effective method for estimating runoff characteristics from ungauged basins with limited information. The principal aim of the procedure is to calculate peak discharge resulting from extreme rainfall events. In the current study this is not the primary interest and the analysis was initiated with the idea of transforming the CN into a preure for estimating the amount of surface runoff generated during different time steps. Similarly, the calculation of runoff coefficients employing a combination of data on soil type, slope and vegetation characteristics can be used to predict the runoff volumes within sub-basins. However, the key requirement for the Thornes erosion model is the amount of the precipitation which moves as overland flow during each time step.

Ali and de Boer (2010) used a hydrological sub-model to predict the surface runoff in each time step (in their case the time step was monthly). The sub-model is essentially a reservoir water balance model which computes saturation-excess surface runoff by considering the retention capacity of the soil, soil moisture and potential evapotranspiration relative to precipitation input. As the soil moisture increases during the monsoon season the probability of surface runoff increases. However, in the absence of reliable data on any of the variables above, it is difficult to use the sub-model to estimate runoff. Additionally, the limited time available to complete the analysis makes is problematic to construct and calibrate a runoff sub-model. A simplifying assumption is therefore required. Experimenting with the sub-model suggests that the surface runoff coefficient would be about 0.01 (1%). For the purpose of demonstrating the erosion model, a decision was made to compute the runoff by applying an annual runoff coefficient to the rainfall distribution in Figure 6.12.

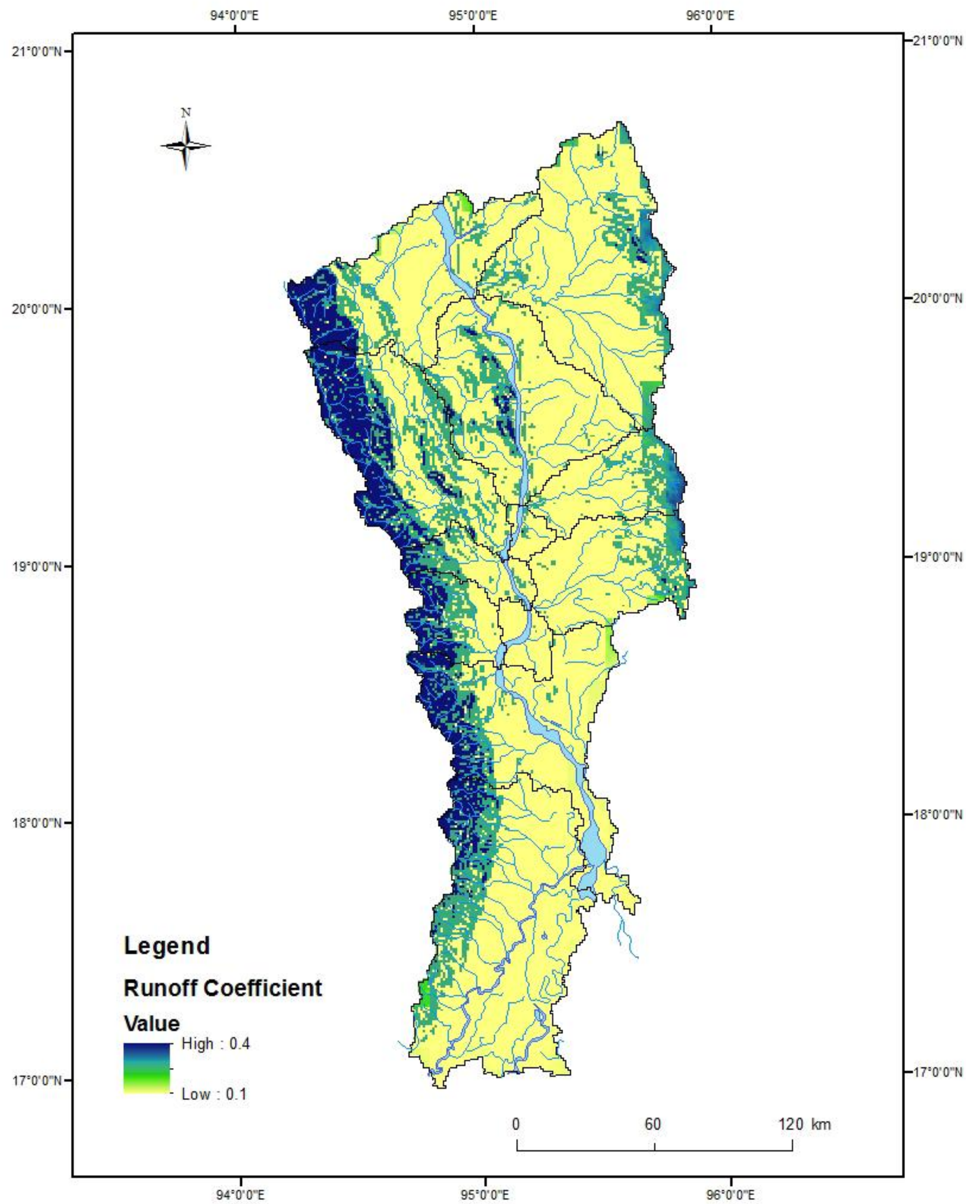


Figure 6.13 SCS Rainfall and Runoff coefficient in Lower Irrawaddy basin

6.8 Vegetation cover changes in the Lower Irrawaddy basin

Vegetation cover is a necessary input for the Thornes Soil Erosion model for the Lower Irrawaddy basin. In Chapter 5, a time series analysis of all land cover changes in the study area was presented. In this chapter, change detection in the analysis of vegetation cover is emphasized in calculating the landsat image of 1989 and 2003. Land cover and vegetation can be derived from remote sensing information. Vegetation cover can be derived from Normalized vegetation Index (NDVI) images. NDVI is currently the only globally available remote sensing estimate of vegetation cover. Cover was calculated from NDVI using the following regression relationship derived by collating the study area of the Lower Irrawaddy basin. When the spatial resolution of the image is reduced to a point when it exceeds the size of the plant, the predicted erosion is reduced because some of the vegetation cover of the plants is assigned to the bare area between them.

6.8.1 Normalized Difference Vegetation Index (NDVI)

Vegetation cover is the one of the most important factors influencing soil erosion rates and therefore providing erosion control. The spatial estimation of the vegetation cover factor can be estimated using vegetation indices derived from satellite images of study area. The normalized difference vegetation index (NDVI) is one of the most widely used vegetation indexes and its utility in satellite assessment and monitoring of global vegetation cover has been well demonstrated for several years over the decades (Sader et al., 1992; Huete and Liu, 1994; Leprieur et al., 2000). A time series analysis of 1989 and 2003 NDVI were derived from Landsat 7 TM images acquired on January, February, March and December of study area. The land cover changes using Landsat data and ENVI images analysis of Lower Irrawaddy basin area were calculated using those NDVI images (Fig 6.15 and 6.16, Table 6.8). Change detection is an important tool in many remote sensing applications. The study assessed changes in vegetation cover over a 14 year period. This study also sought to estimate vegetation factor values of land cover classes using NDVI values by sediment analysis for erosion modeling in lower Irrawaddy basin. The Landsat images are calculating with Vegetation Indices to estimate (V) factor values of land cover classes using NDVI values for modeling soil erosion using ENVI and ArcGIS 10 software. The spectral reflectance difference between Near Infrared (NIR) and red is used to calculate NDVI. Figure 6.14 and Figure 6.15 shows the NDVI image of the Lower Irrawaddy basin in 1989 and 2003. The Landsat TM reflectance bands 3 and 4 were used to generate the NDVI image using the formula described below:

NDVI = (band 4 – band 3) / (band 4 + band 3)

Table 6.8 Minimum, Maximum, Mean and Standard deviation of NDVI (1989 and 2003)

(NDVI)Image	Min	Max	Mean	Stdev
1989 (91,587,520 Pixel points)	-0.945946	0.967213	0.151055	0.209251
2003 (330,635,720 Pixel points)	-0.982759	0.982456	0.066936	0.139639

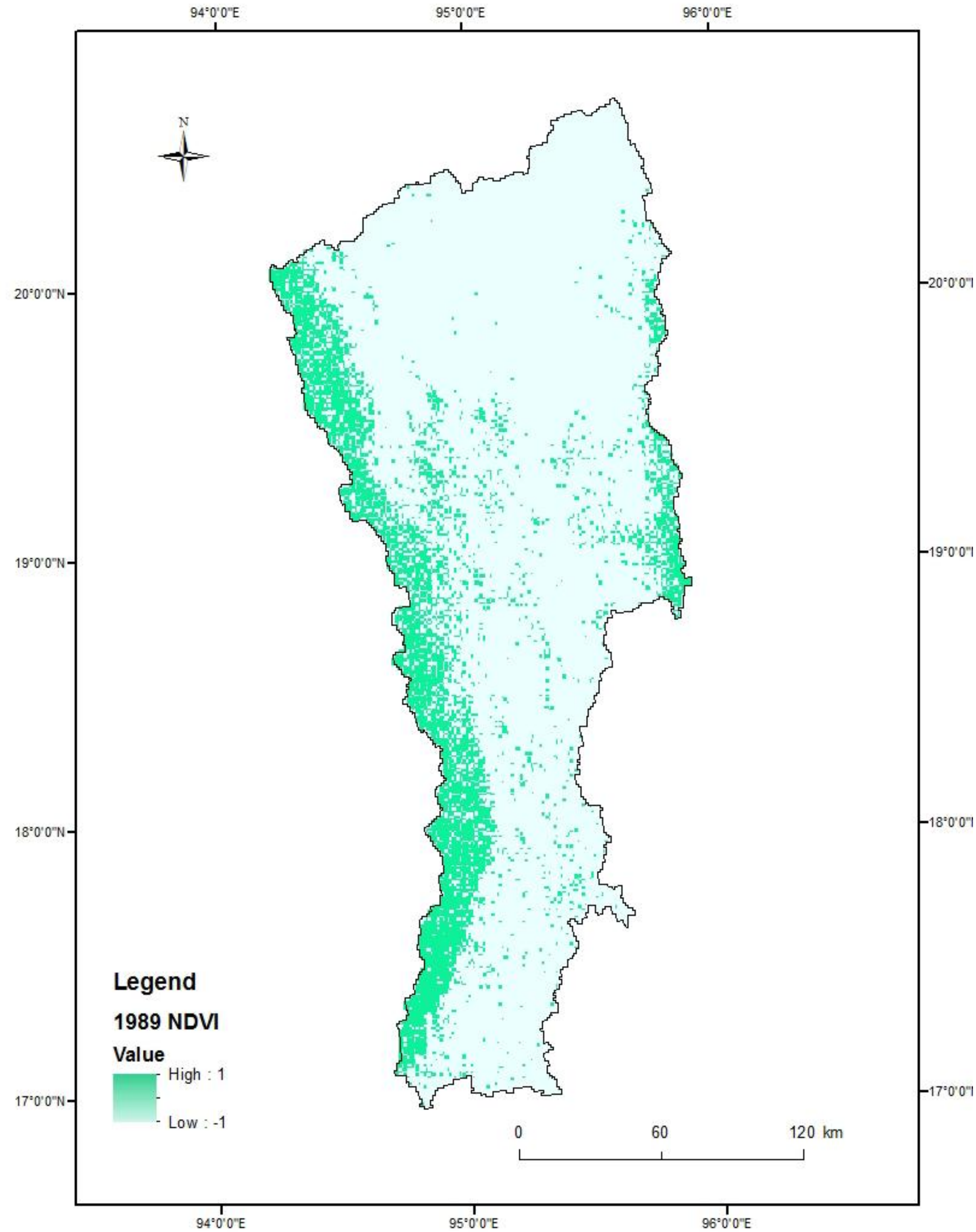


Figure 6.14 NDVI images of the Lower Irrawaddy basin for 1989

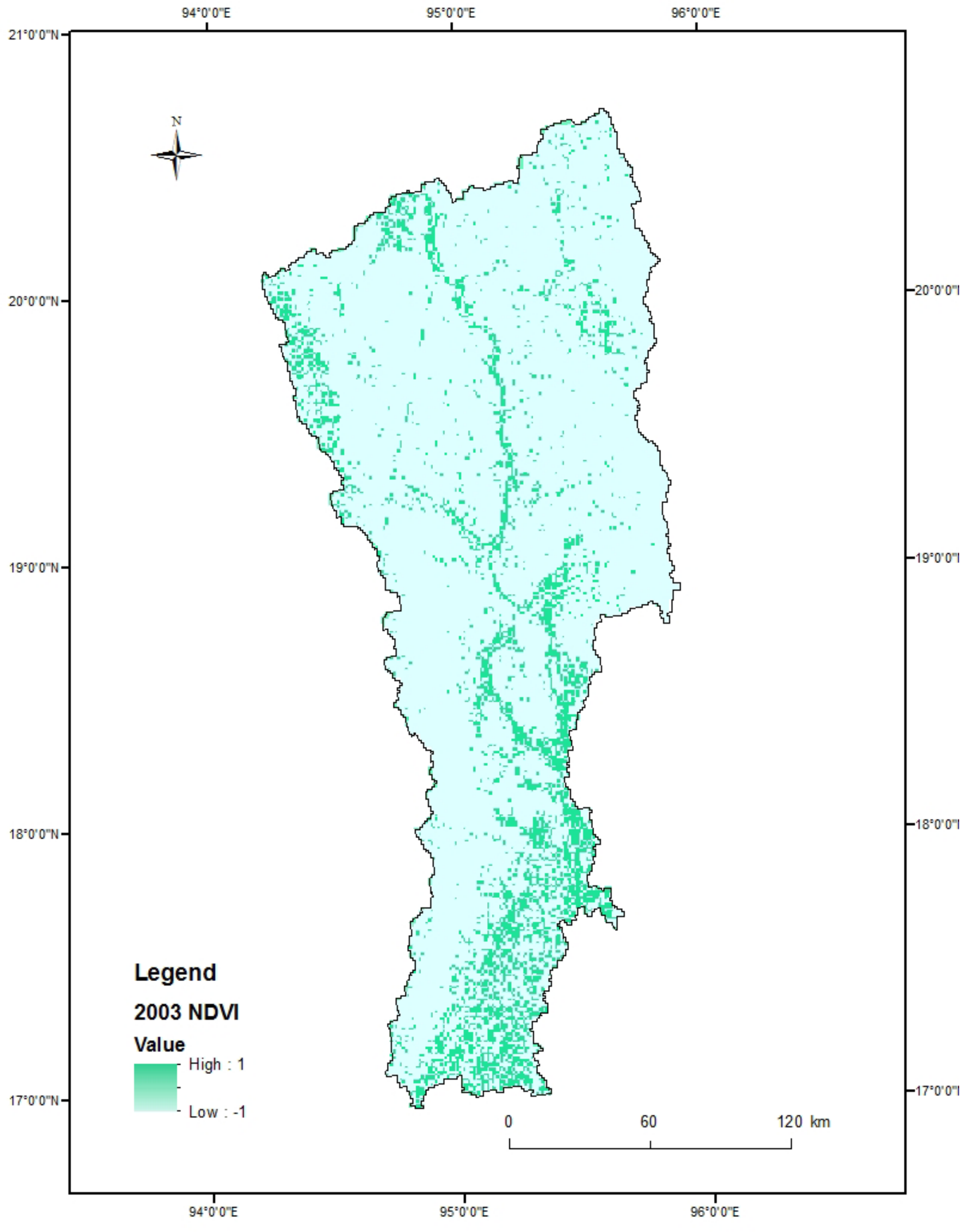


Figure 6.15 NDVI images of the Lower Irrawaddy basin for 2003

6.8.2 Change Detection Analysis (1989-2003) of Vegetation Cover in the Lower Irrawaddy basin

NDVI (Normalized Difference Vegetation Index) values range from -1.0 to 1.0, where higher values are for green vegetation and low values for other common surface materials. Bare soil is represented with NDVI values which are closest to 0 and water bodies are represented with negative NDVI values (Lillesand et al., 2004; Sesnie et al., 2008). There are many other vegetation indicators, but NDVI is the most commonly used and the calculated NDVI is values proved useful in this application. The study result range shows in value from-1 to 1 (Unchanged to Changed), where the higher values indicate pixels of green vegetation and the lighter values have no vegetation change (Figure 6.16).

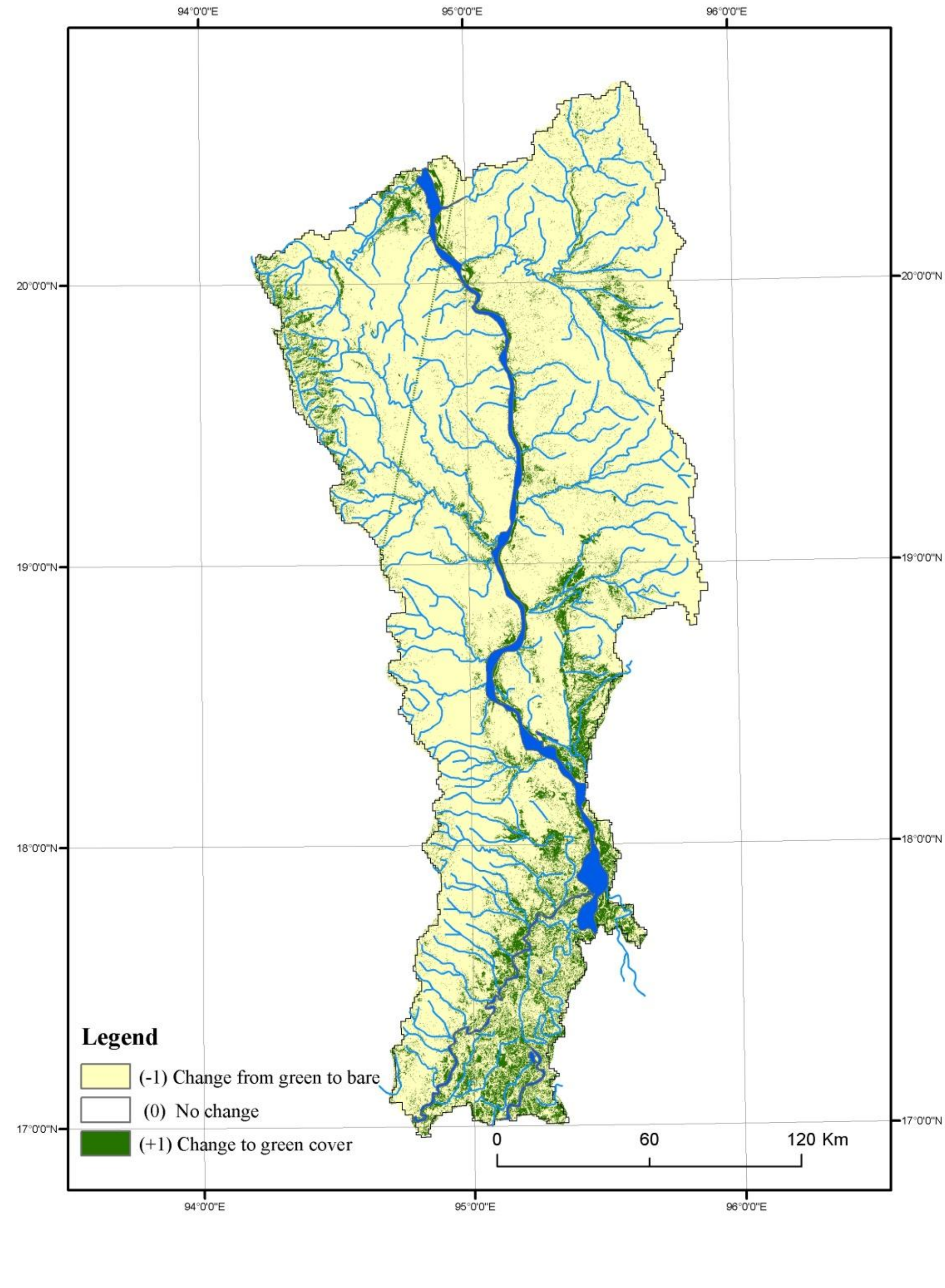


Figure 6.16 NDVI Vegetation change in Lower Irrawaddy basin

6.8.3 NDVI Index and Change Detection Analysis

The Normalized Difference Vegetation Index (NDVI) gives a measure of the vegetative cover on the land surface over wide areas. Applying this technique is in conjunction with change detection analysis of vegetation cover change 1989 to 2003.

Figure 6.17 shows NDVI change detection analysis model tools in ArcGIS spatial analysis. The study area shows the characteristic of the central area with agriculture lands. Mostly, the area is generally rural and surrounding of farmlands and extended suburban built up areas. A higher value shows the high vegetation areas like forest, which is basically confined to north-west hilly areas of Irrawaddy basin. The cultivated fields also show quite high NDVI values as compared to barren lands, which are basically confined along the Irrawaddy River and streams. Negative impact is clearly observed as the dense forest has suffered degradation. It is the result of increased human intervention through agriculture, settlement and other activities. The lower reaches of Irrawaddy basin have high proportion of agricultural land which shows positive NDVI values. To some extent, the facilities of irrigation along the river basin have improved as a result the area under cultivation along the river basin has increased. The lower value shows non-vegetation areas like barren land, water bodies and settlement. At a few places, the negative index values have disappeared for the degraded land for the year 2003. It is observed through Change detection analysis but still the impact is not satisfactory enough. The lower reach of study basin has a high proportion of agricultural land and low proportion of barren land vegetation.

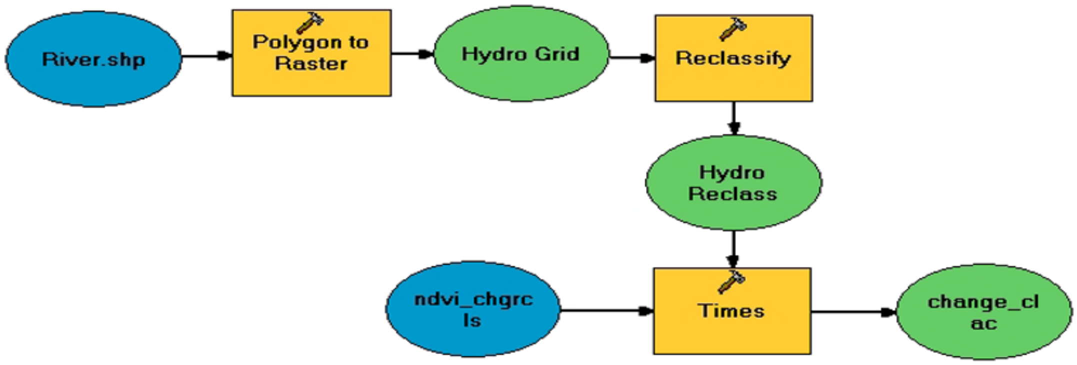


Figure 6.17 NDVI change detection analysis model tools in ArcGIS

6.8.4 Change detection analysis

During the period of analysis, the substantial change in vegetation cover has been observed in Lower Irrawaddy basin. The net area of forest cover has been reduced by 6942 km^2. The change area is specifically south-east of study area. The floodplain vegetation areas (650 km^2) have not shown any substantial change as the NDVI changes of the vegetation index of these areas are below 0.10. The satellite images of study region acquired during 1989-2003 periods have offered a rich source of information about changes in land use /land cover and NDVI index in the lower Irrawaddy basin over a period of 14 years.

The normalized difference vegetation Index (NDVI) can use for estimating temporal vegetation cover study and it is one of the vegetation indicates measure the amount of green vegetation. NDVI values range from -1.0 to 1.0, where higher value is green vegetation and low values from the surface materials. Barren land is represented with NDVI value which is closest to 0 and water bodies are represented vegetative values. The vegetation cover factor enables to assign the various studies shows that factor is relationship between v and NDVI (Drake et al., 1999, Malthus et al., 1993 and Blackburn and Milton (1995). The vegetation cover index (v) percentage can be converted from the NDVI data using the following the regression equation:

$$Vc = 93.07466 * NDVI + 8.79815$$

NDVI values from the 1989 Landsat image were used to calculate the percentage vegetation cover for the study area in Figure 6.18.

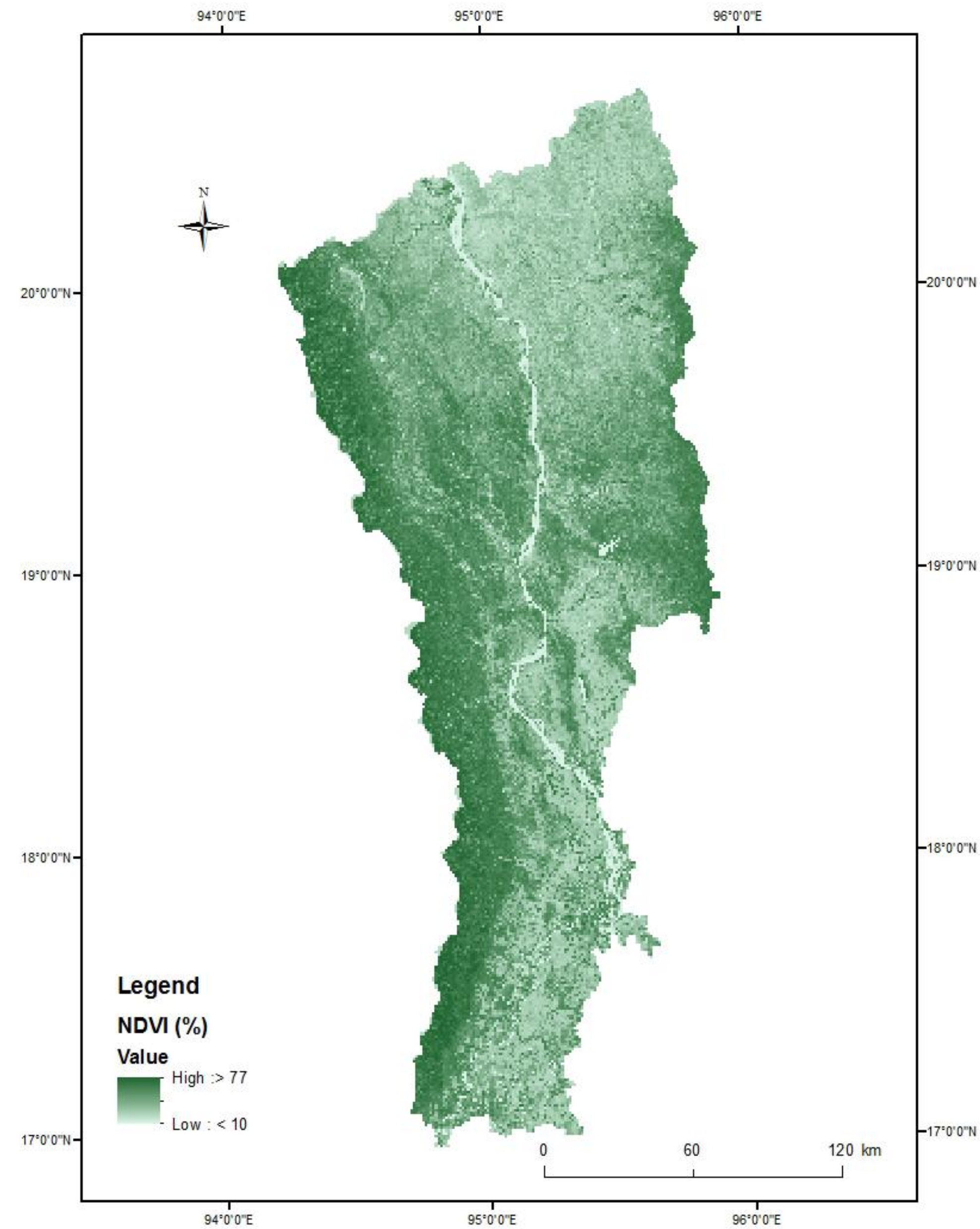


Figure 6.18 Vegetation cover for the Lower Irrawaddy basin (1989)

6.9 Modelling Erosion rates in the Lower Irrawaddy basin

The rate of soil erosion within the Lower Irrawaddy basin can be estimated by implementation of the Thornes Erosion Model given in Equation 6.1.

In the previous sections, the range of values for each of the four variables has been extracted. The percentage of vegetation cover (**VC**) has been derived from a regression equation applied to NDVI data. Slope gradient (S) is derived from DEM in GIS. Soil erodibility (**k**) is based on matching the texture class of soils derived from the FAO world soil map. The variable (**Q**) is overland flow (mm) derived from annual rainfall maps. The rate of erosion calculation for the Thornes erosion model for the respectively factors are have been estimated in the each sections. The Soil erodibility factor (K) for section 6.7 has been estimated. Soil erodibility is derived from the primary soil texture and organic matter content form the different soil types of study area. Soil erodibility determination value is 0.04 to 0.3 in the lower Irrawaddy basin.

Runoff factor of is based on a runoff coefficient applied to the spatial rainfall distribution. The annual rainfall varies from 759.01 to 1569.2 mm across the lower Irrawaddy basin. Slope (S) factor (gradient) is calculated as the tangent of sope angle insection 6.6. The slope gradient ranges from 0 to 0.4 in the study area. The vegetation cover (Vc) has been estimated in Section 6.8. In the equation the percentage vegetation cover is transformed by calculating $e^{-0.07VC}$. This transformed value ranges from 0.0009 to 0.6158 across the study area.

As the preceding sections have demonstrated, the estimation of all four variables raises some significant uncertainties about the accuracy and appropriateness of data. In the absence of a detailed soil survey of the region, the FAO soil information has poor resolution and the distribution of erodibility in blocky. The dynamic status of variables is also a concern. Within the Thornes erosion model the coefficient of erodibility (K) and slope gradient (S) are constants which do not change over inter-annual time scales. However, both vegetation cover and surface runoff generation will display marked seasonal variations. In the procedure outline by Ali and De Boer (2010) which has influenced the approach here, the authors use a monthly time step to overcome the seasonal variation. Thus the NDVI composites are used to compute vegetation cover at different times of the year, while the hydrological sub-model computes a surface runoff depth (mm) in monthly time steps. The erosion model is then computed for individual months and summed to give the annual erosion rate. It was the intention to follow the monthly time step procedure here but there were limitations of the reliability of the runoff estimates given the paucity of rainfall records. Also time to revise the calculations was limited and so a decision was made to run the model at an annual time step for demonstration.

The erosion model was applied at 1km spatial scale resolution and at an annual resolution for calculating the annual erosion rate mm/year. Since the processing of each output maps involves use of a raster calculate to extract values from each layer, it is necessary to use a common pixel distribution and working window. Figure 6.19 shows the spatial distributions of predicted annual erosion rates in the lower Irrawaddy basin. The spatial patterns of predicted annual erosion rate observed 0.0 to 21.0 mm/year. The predicted erosion rates are highest in the left bank tributaries in the north of the study area and adjacent to the river in the south of the study area. The former may be unduly influenced by the high erodibility factor attributed to the loamy texture in this region. The latter may be baised by the high rainfall total (and hence runoff) and the low vegetation cover in this part of the basin. The observed results seem reasonable but tend towards overestimation. It is likely that this is due to overestimation of the annual runoff in each pixel. It is also a function of the poor resolution of using an annual time step. If a smaller (e.g. monthly) time step were used the higher runoff values in the monsoon months would be counterbalanced by the higher vegetation cover in the wet season. Time restriction necessitated using an annual time step but on going work will attempt to refine the runoff estimation and deploy a monthly time step. It is also possible to run iterations of the model against the historical reconstruction of land use change to examine how erosion rates may have responded to forest clearance.

From the erosion distribution it is possible to calculate the mean erosion rate in each of the twelve sub-basins. he sub-basin erosion rates are influence by the different characteristics of the regional topography and vegetation cover. Figure 6.20 shows sub-basin annual erosion rates in the lower Irrawaddy basin. As the study area is dominated by arable cultivation, the most sensitive factor in the Thornes erosion model would be vegetation cover. It is directly affected by human activities. Owing to time limitations, the analysis used the vegetation cover percentage from the1989 landsat image through the calculation of NDVI. This is a limitation and ongoing work will attempt to derive vegetation cover maps for monthly time steps as well. The maximum, minimum, mean and standard deviation of erosion rates of the lower Irrawaddy sub-basin are also shown in Table 6.9.

Table 6.9 Erosion Rates for the Lower Irrawaddy basin

Basin	**Area(km2)**	**Erosion Rate(mm/year)**			
		Max	**Min**	**Mean**	**Std**
1	4086.07	8.95	0.00	3.45	2.08
2	6173.35	11.67	0.00	5.18	2.31
3	4722.68	12.91	0.00	5.45	2.20
4	1855.43	7.03	0.00	2.91	1.51
5	4433.31	6.86	0.00	1.42	1.38
6	347.85	4.84	0.00	3.23	0.99
7	1004.05	5.63	0.00	1.87	1.56
8	2723.33	4.85	0.00	1.58	1.24
9	1280.68	4.19	0.13	1.06	0.94
10	581.62	5.20	0.00	3.77	0.93
11	4754.98	21.05	0.00	4.03	4.07
12	7438.52	13.32	0.00	3.82	3.14

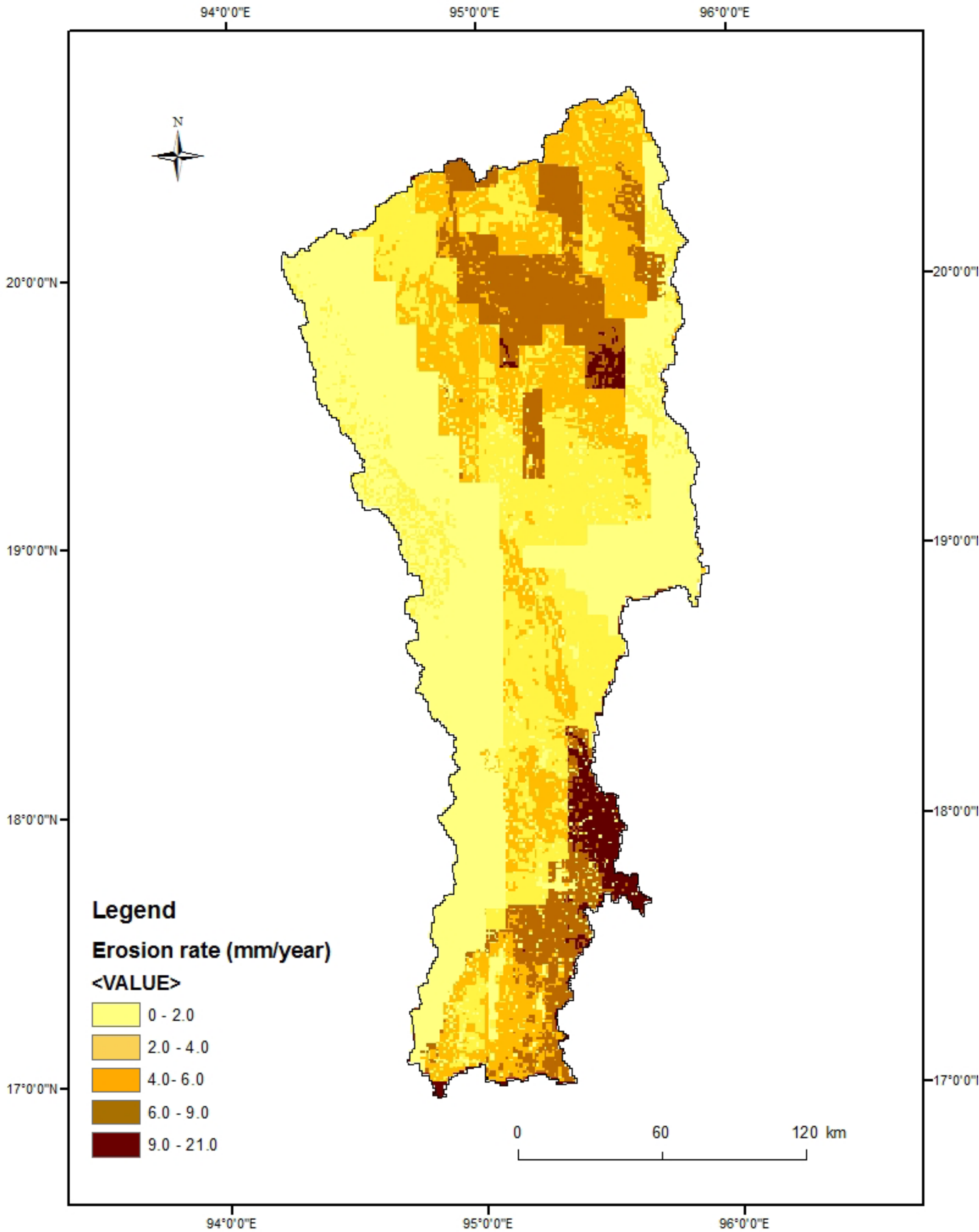


Figure 6.19 Spatial distributions of predicted annual erosion rates in the lower Irrawaddy basin

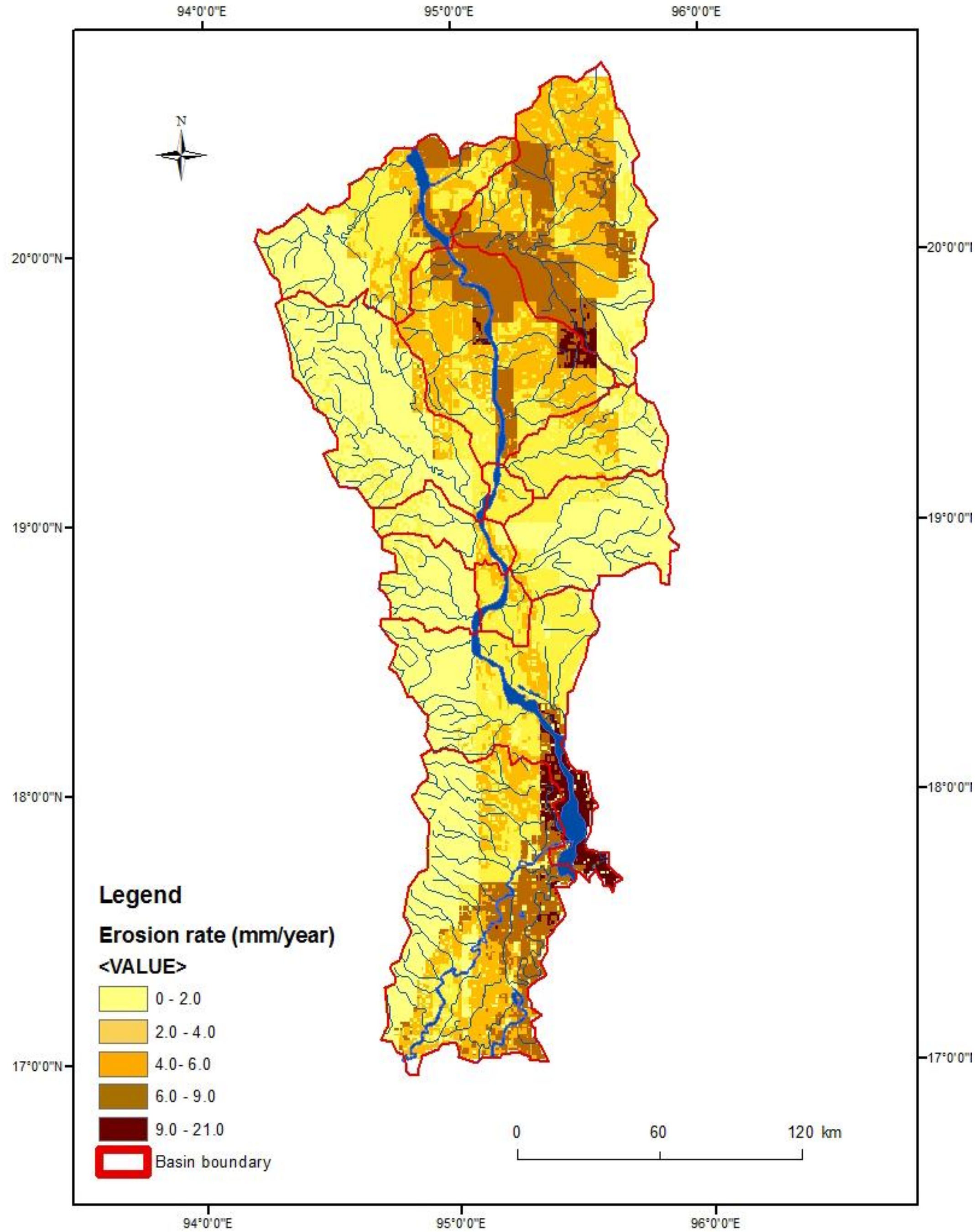


Figure 6.20 Sub-Basins and annual erosion rates in the lower Irrawaddy basin

To summarize, the methodology developed in this research allows each layer to be independently updated in watershed digital map from if resources are available. Throughout this hydrological analysis, assumptions have been made due to both the limitations of data and the models that have been used. In this study, having only five rain gauge stations in the catchment made it difficult to interpolate the rainfall for the entire catchment. The determination of runoff for the Lower Irrawaddy basin using GIS and SCS-CN methods was described. The regional scale erosion model has been a limited validation of Thornes model parameters as well as outputs. For obtaining more accurate erosion estimates better resolution data sets are required and the seasonal range of dynamic variables (runoff, vegetation cover) should be taken into account. Field data could supplement the extraction of information from databases, especially in relation to soil erodibility. The analysis can be extended further to assess the impact of change in land cover over a period time on rainfall runoff and soil erosion. This approach could be applied in other watersheds for planning of various conservation measures.

7. DISCHARGE AND SUSPENDED SEDIMENT FLUX IN THE LOWER IRRAWADDY BASIN

7.1 Introduction

The majority of a river's sediment load is carried in solution as dissolved load or in suspended load. Sediment budget analysis consists of the evaluation of sediment fluxes, sources and sinks from different processes. Sediment load of a river provides an important measure of its morphological dynamics, the hydrology of its drainage basin and the erosion and sediment delivery processes operating within that basin. The magnitude of the sediment loads transported by rivers has important implications for the functioning of the system, for example through their influence on material fluxes, geochemical cycling, water quality, channel morphology, delta development, and the aquatic ecosystems and habitats supported by the river (Walling, 2006). Suspended sediment load is a useful indicator for assessing the effects of land cover changes and engineering practices in watercourses. The investigation of the trend in the sediment loads has different constraints in terms of available data. The study of river suspended sediments is becoming more important and it is one of the most serious environmental problems of sequences of soil erosion. However, erosion is a natural phenomenon and the high rate of soil erosion is increased by agriculture, land use change and other human impacts. Generally, this may be effect on suspended sediment loads in the rivers. The Irrawaddy is one of the least understood large Asian rivers in terms of its suspended sediment dynamics. Continuous monitoring is essential to effectively measure suspended sediment loads to describe sediment transport dynamics accurately.

The goal of this study is to investigate water discharge and the suspended sediment transport from upstream into the Lower Irrawaddy basin. A wide variety of techniques have been used to measure suspended sediment concentration (SSC) in rivers, most common methods are conventional samplers, optical method instruments and acoustic Doppler instruments. In this study, the Acoustic Doppler Current Profiler (ADCP) is used to collect water velocity and also to assess suspended sediment. The optical instruments use the turbidity of the water as an indicator for the concentration of suspended sediment in the water column. Water sampling is necessary for water quality monitoring and analysis of suspended sediment flux. This study will present the results and calibration method of ADCP data collected examining sediment concentration and suspended sediment fluxes moving through a diversion river channel crosses-section at three sites in the lower basin of Irrawaddy River.

7. 2 Location of study sites and Methods

The study sites are located in central part of Lower Irrawaddy basin. Pyay is about 300 km north of the Gulf of Martaban and the Andaman Sea. The river here is ~35m mid-depth with a relatively flat bottom and ~1000 m width. Field data were collected at Pyay at three sites. Site-1 was chosen for the installation of a gauging station as part of the Yangon-St Andrews international project. However, there are some complex flow patterns at this site as the river width narrows downstream of a large bend. A second site (site-2) was therefore also surveyed, downstream of Nawaday Bridge where the cross section is more regular. Sampling site-3 is at Seiktha which is about 50 km downstream of Pyay. This is the original sampling site used by Gordon for the monitoring work in the nineteenth century (Gordon, 1885; Robinson et al., 2007). The locations of the three sites are shown in Figure 7.1. Table 7.1 shows the Latitude and Longitude of the two sites at Pyay and one at Seiktha.

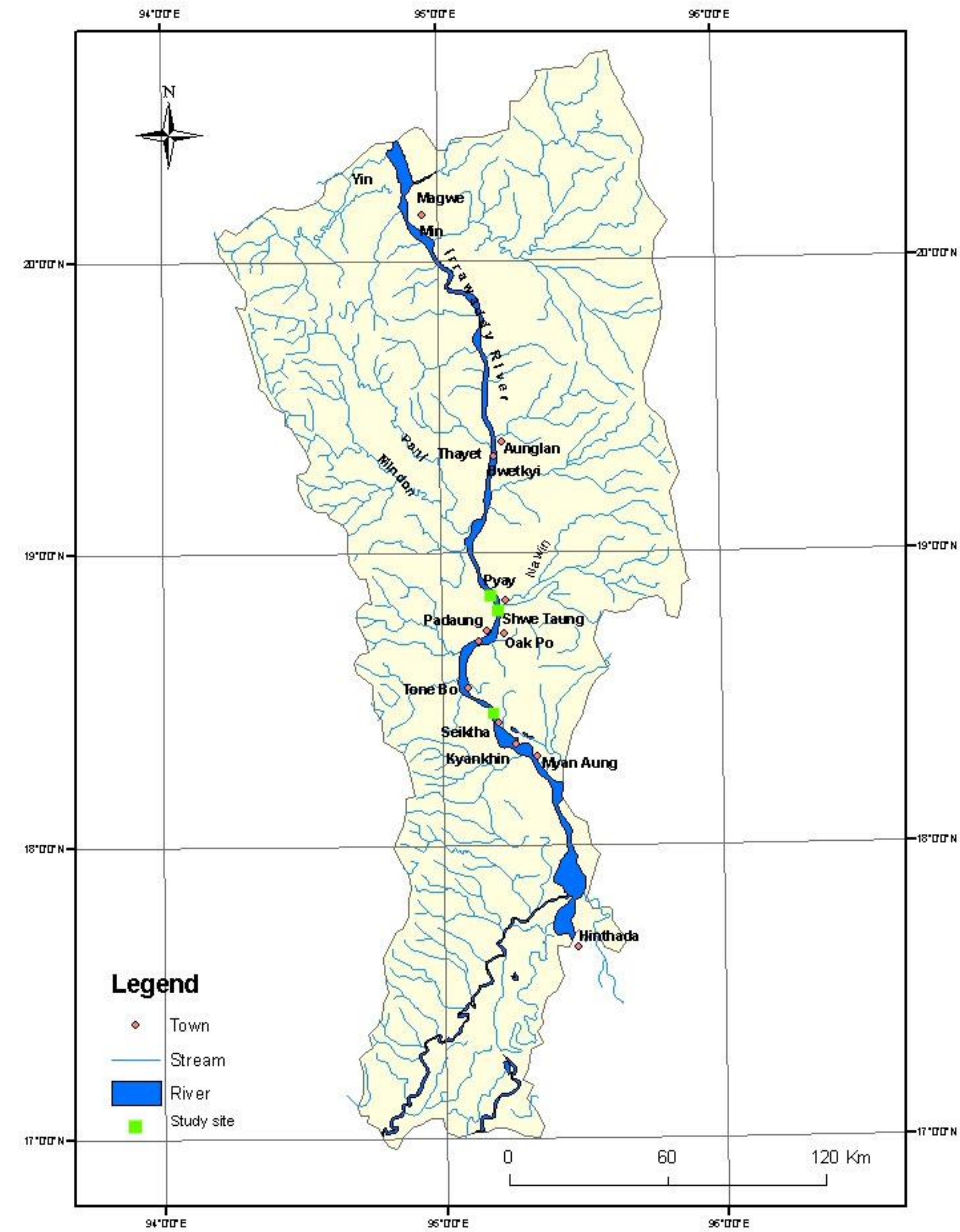


Figure 7.1 Location of the two study sites at Pyay and the original study site of Gordon (1879-1885) at Seiktha of the Lower Irrawaddy basin

Table 7.1 Latitude and longitude of the three sampling sites, Coordinates are in WGS84

Sampling Site	Sampling Start	Sampling End	Latitude	Longitude
Site_1(Pyay)	3/4/2011	5/4/2011	18^{o} 49' 41.81"	95^{o} 12' 69.21"
Site_2(Pyay)	1/4/2011	5/4/2011	18^{o} 48' 26.35"	95^{o} 12' 30.48"
Site_3(Seiktha)	1/4/2011	3/4/2011	18^{o} 25' 03.59"	95^{o} 12' 46.62"

The Pyay gauging station (Directorate of Water Resources and Improvement of River Systems, Myanmar) is situated ~ 150 m downstream of Pyay water pump station. As part of the St Andrews-Yangon international project a SEBA pressure transducer depth logger was installed at downstream side of Pyay pumping station (left bank) in May 2006. River water level data were collected from the Pyay SEBA data logger gauged station (Plate 7.1). The project began a process of collecting data on discharge and suspended sediment by measuring cross-sections with ADCP and sampling water from various depths. In the thesis study, additional cross-section surveys have been undertaken. ADCP estimates of discharge for full river cross-sections were achieved by attaching the instrument to a small boat by constructing a raft from bamboo. The corrected data are used to determine water quality, suspended sediment concentration (SSC) and river discharge measurement for the selected sampling dates in the period July 2006 to April 2011. Suspended sediment flux is sensitive to changes in climate and land use, but has received little attention in the lower Irrawaddy basin. However, this study aimed to establish a continuous record of discharge with periodic measurement of TSS and SSC concentration. A short period of study in 2011 is compared with studies conducted by an expedition team from 2006 onwards.

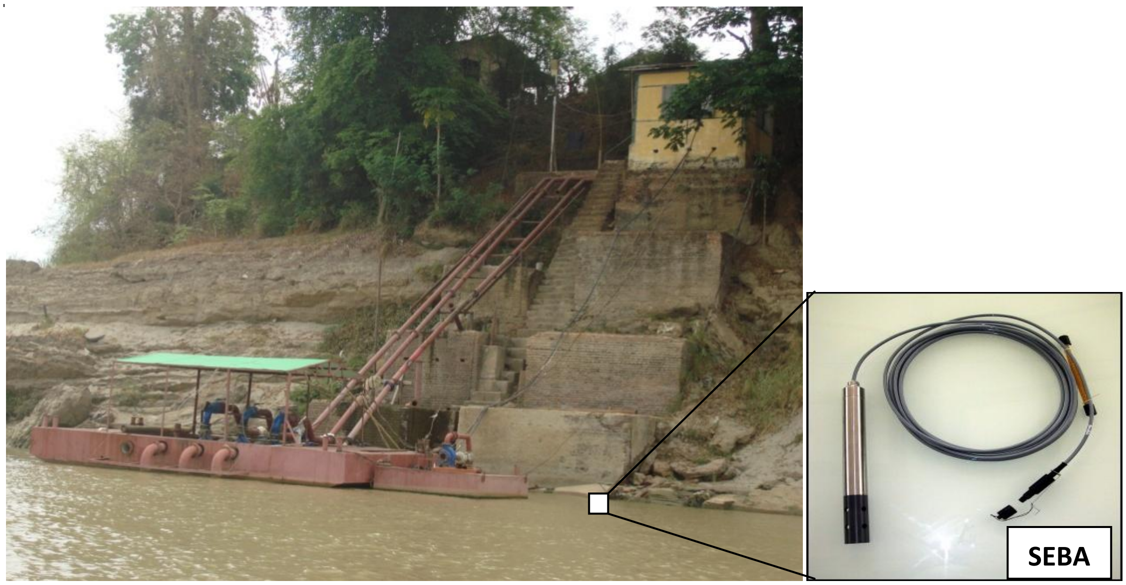


Plate 7.1 Location of SEBA data logger gauged station (Pyay) (Site-1)

7.3 Monitoring Equipment

Transect lines were established to observe flow and sediment flux of the Lower Irrawaddy River (Plate 7.2). Two transect lines were established across the main channel of the Irrawaddy River; Site-1 located upstream of Pyay Station, Site-2 is downstream of Nawaday bridge, Pyay and Site-3 is in Seiktha, 50km downstream of Pyay. At each cross-section, three sampling locations were equally spaced for water samples to be collected.

Plate 7.2 Study sites 1 and 2 at Pyay and Study site-3 at Seiktha

Source: Imagery Date11/19/2004, Elevation 89 ft from Google Earth

Plate 7.3 Discharge measurement using an Acoustic Doppler current profiler (ADCP)

River velocity can change from day to day and year to year. The velocity increases, as runoff washes into the river, carrying with it sediment and other pollutants. The volume of water discharged from a river is a function of the mean velocity and the cross-sectional area of the river channel. The most accurate measurements for large rivers are based on velocity measured by ADCP. The characterization of suspended solids transport in rivers is difficult due to the rapid and unpredictable fluctuations of suspended solids concentrations related to anthropogenic causes or during natural hydrologic events. All velocity, discharge and acoustic backscatter data were collected with a RD Instruments, Inc. (RDI) 600 kHz ADCP (Plate 7.3). The ADCP was mounted on the vessel and lowered so that the transducers were approximately 0.3-0.5m below the water surface. Prior to collecting water samples two ADCP survey lines were run along the two transect lines to collect discharge, average velocity, and acoustic backscatter. The vessel then moved to each water sampling location along the transect line and recorded ADCP data simultaneously while water samples were collected.

7.4 Water Quality Assessment in the lower Irrawaddy River

Water quality data were collected at each of the three sites. Each water sample was collected with a horizontal 2 L Van Dorn sampler at specific depths in the water column (Plate 7.4). In turn, the appropriate depths for sampling water were determined from an echo-sounder. The water sampling strategy mimics the original programme of Gordon. Samples were collected at three depths: 1 m below surface, mid-depth and 1 m above bed of river. There are three sampling positions in mid-channel and midway between centre and the banks. Hence there are 9 samples (3 positions x 3 depths) for each cross-section. In this study to supplement the data collected by the international project, 12 cross-sections were measured and hence 108 water sample bottles (1 Liter) were collected. Water quality analysis of the turbidity, temperature, conductivity, and pH of each sample were determined immediately upon collection. The water quality was calibrated with Accumet water quality tester (Plate 7.5). Sample locations were determined by Garmin GPS and water depths at each sample location were determined by dual frequency Lowrance depth sounder.

Plate 7.4 Horizontal 2 L Van Dorn sampler and water sample bottles

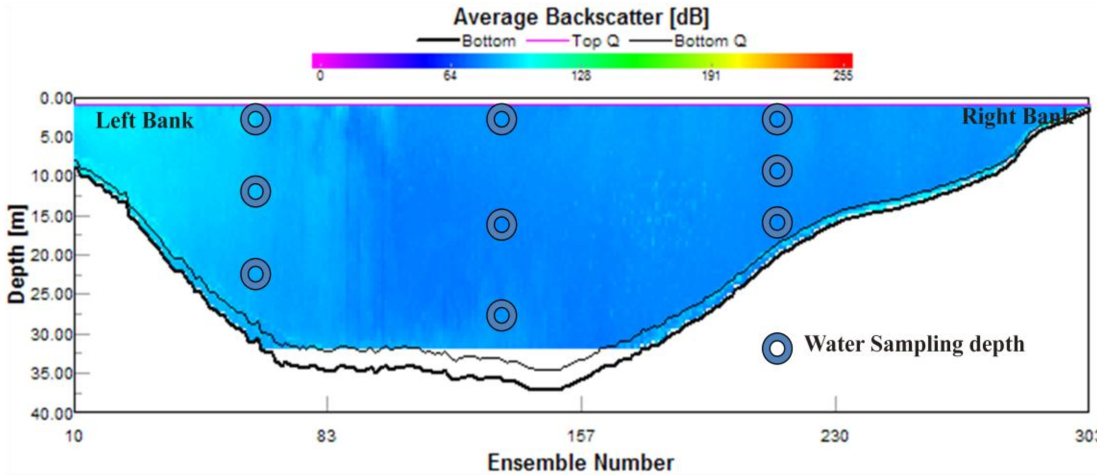


Figure 7.2 Illustration of water sampling collecting depth in study site

Plate 7.5 Water quality testing equipment

Water samples were taken at the study sites of Pyay and Seiktha in 2007 and 2011. All water samples were collected in clean 1L plastic bottles. At each collection point three samples at 1 m depth-surface, mid-depth and 1m bottom-depth were collected with a horizontal 2L Van Dorn Sampler (Figure 7.2). This three depth strategy was followed also by Gordon (1870) and Robinson et al., (2007) in their Irrawaddy River research. The total numbers of 108 samples were filtered on sites of Pyay and Seiktha. Once the sediment had settled, the remaining water was decanted from the container, and the sample was stored in a high-concentration for TSS analysis. After filtering samples were stored in a cool place and transported back to the laboratory for analysis. Total suspended solids (TSS) are defined as the portion of total solids in water sample retained by Whatman Glass microfibre filters (nominal pore diameter 47mm, Cat No.182.5 070). The sediment sampling methods consist of collection of field water samples in bottles, filtering them to separate out the suspended matter and determine its mass in reach to the volume of sample. Although, the methods proved mainly reliable and accurate, there were same disadvantages. The method is time-consuming and labour-intensive. Additionally, the water samples need to be preserved suspended sediment concentration and analyzed in the laboratory.

The use of turbidity as a surrogate for suspended sediment concentrations has become more common, such as in several studies in the stream and rivers. Turbidity is the physical property of reduced light transmission through water due to absorbencies and scattering by solid particles in suspension. Very fine dissolved solids can also contribute to turbidity. Streams and rivers are normally much more turbid than are still waters in lakes and reservoirs. In this study, measured turbidity data for December 2006 and June 2007 are presented for Seiktha and Pyay. Water temperature has both direct and indirect effects on aquatic ecosystems. Variations in water temperature occur both seasonally and daily. Water temperature is a major factor in determining which species are present in the streams and rivers. However, the temperature of water changes, chemical and physical properties of the streams and rivers are affected. Conductivity, pH, and gas solubility are temperature dependent. Temperature (^{o}C) is a critical water quality parameter, since it directly influences the amount of dissolved oxygen that is available to aquatic organisms. A multi-probe YSI 6600 EDS was used to log temperature, pressure and turbidity continuously while undertaking the sampling at Seiktha and Pyay (2006 to 2007). The data are provided in Appendix D. At Pyay, the average temperature was 25^{o}C and turbidity was 184 FTU in December 2006 (Figure 7.3); the average temperature was 30^{o}C and turbidity was 528 FTU in July 2007 (Figure 7.4). At the study site at Seiktha, the average temperature was 25^{o}C and turbidity was 180 FTU in December 2006 (Figure 7.5) and average temperature was 27^{o}C and turbidity was 450 FTU in July 2007 (Figure 7.6). Temperature and turbidity vary seasonally and affect the water quality of the Irrawaddy River.

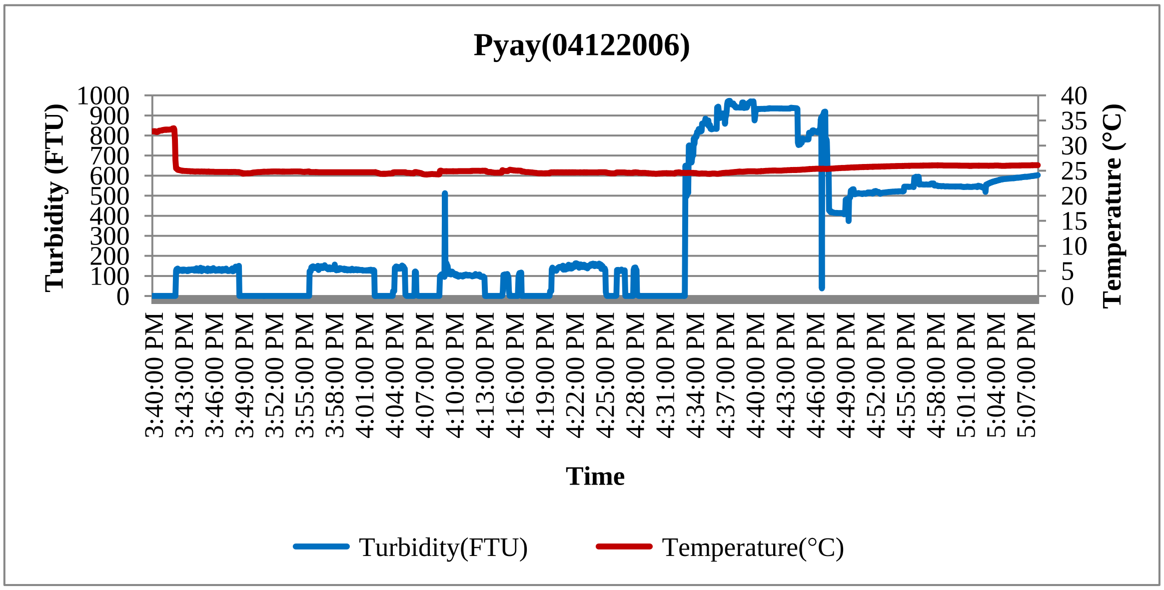


Figure 7.3 Turbidity and Temperature variation in Pyay on 4th December 2006

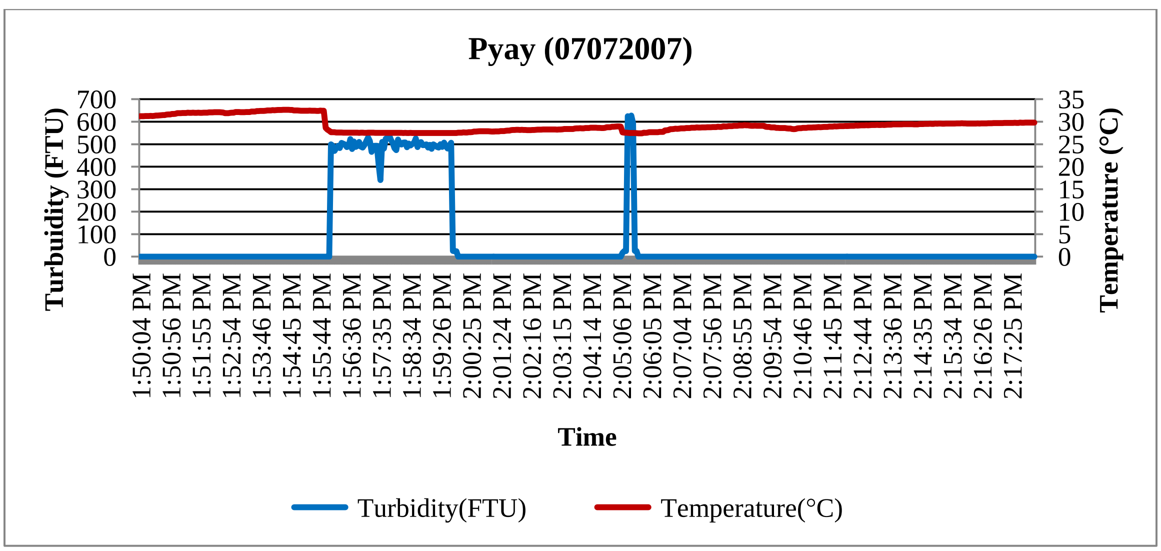


Figure 7.4 Turbidity and Temperature variation in Pyay on 7th July 2007

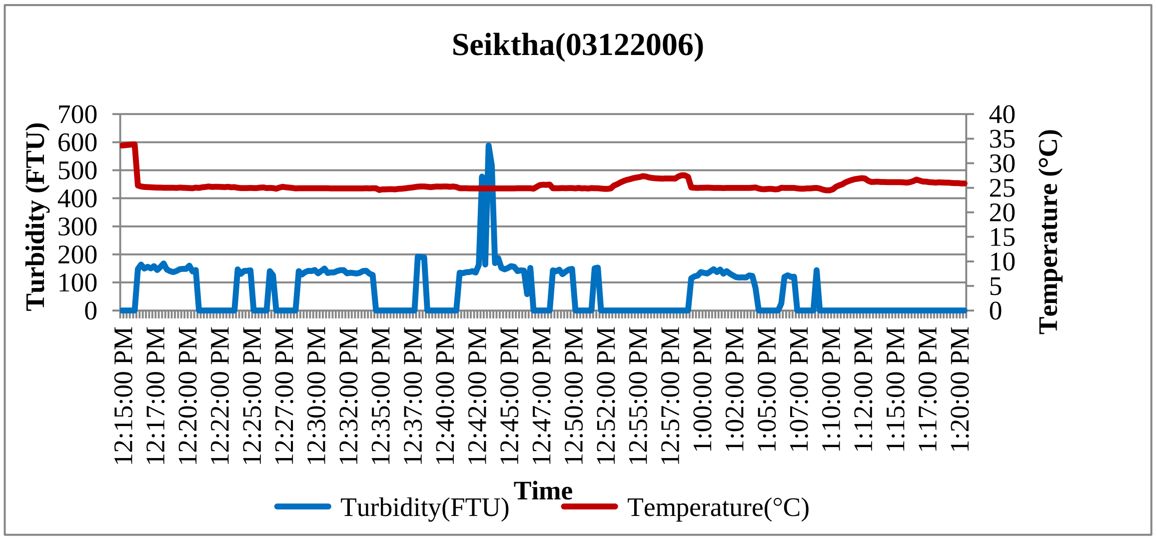


Figure 7.5 Turbidity and Temperature variation in Seiktha on 3rd December 2006

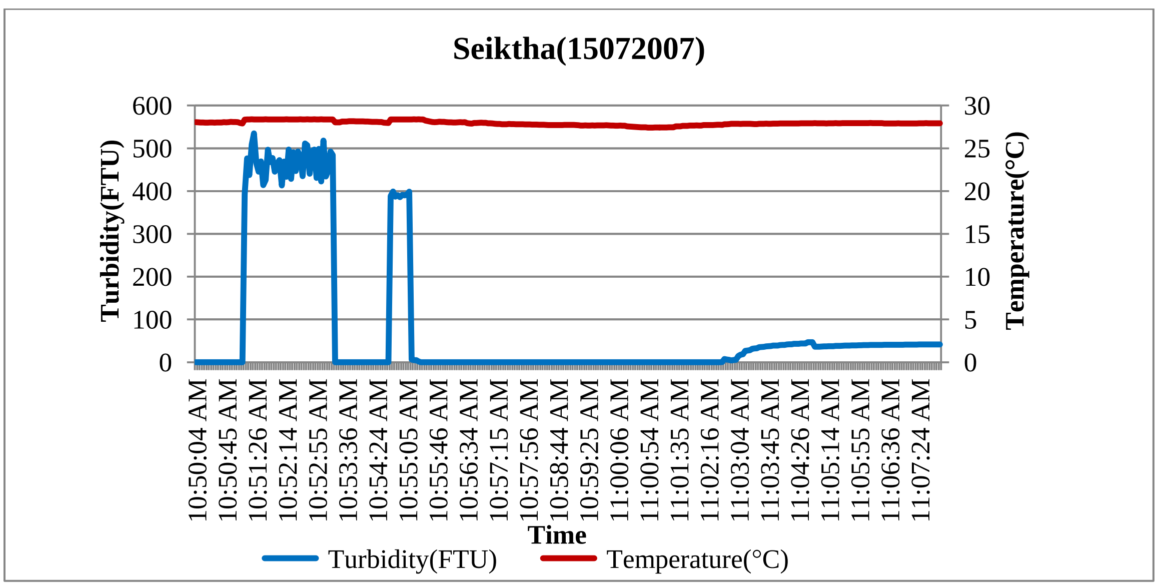
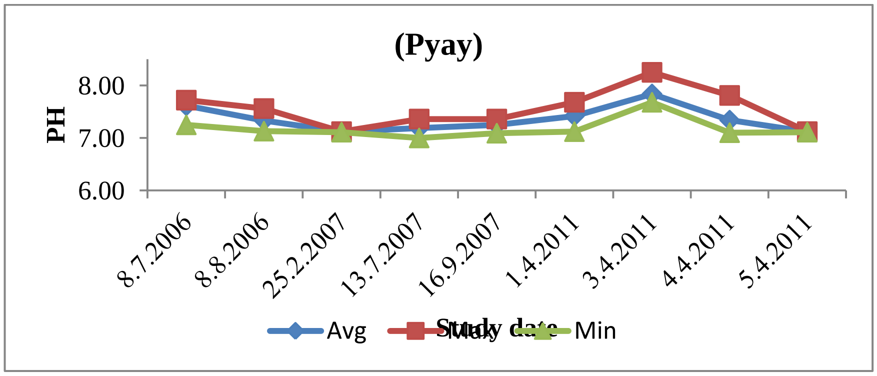
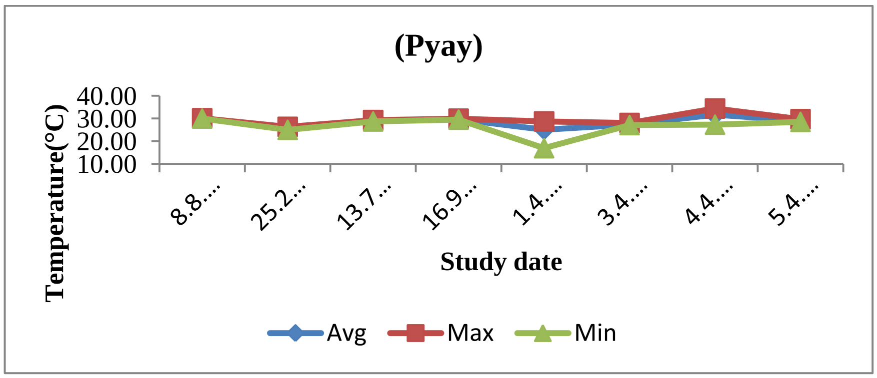


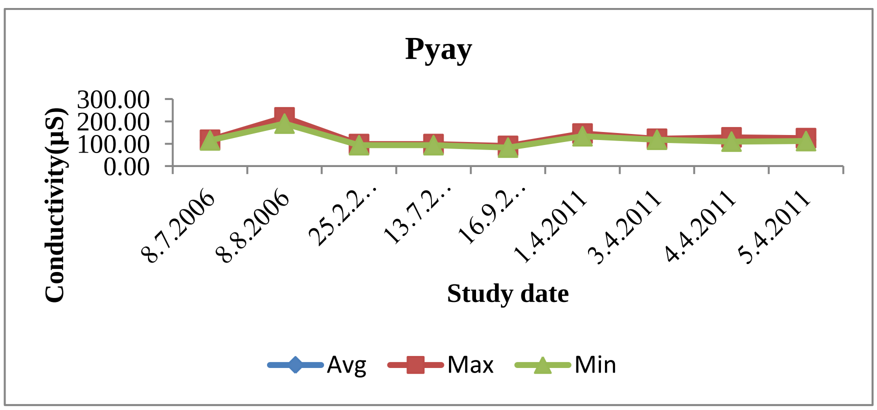
Figure 7.6 Turbidity and Temperature variation in Seiktha on 15th July 2007

Water sampling and water quality testing

Water quality monitoring results were derived from water sampling in July 2006, June and September 2007 and April 2011. The samples collected in April 2011 were undertaken as part of the thesis to supplement the previous measurements from the international project. There are 18 water samples for each study site per study day from 1.04.2011 to 5.04.2011. These water samples are taken from the three depths at three locations within the cross section. Temperature, pH, Conductivity, TDS and Total Suspended Sediment data were collected in the field and TSS in the laboratory analysis. pH (potential of hydrogen) is a measure of the concentration of hydrogen ions in the water. This measurement indicates the acidity or alkalinity of the water. The pH is important because it affects the solubility and availability of nutrients, and how they can be utilized by aquatic organisms. The average pH value is 7.2 and temperature is 26.7^{o}C. Conductivity is affected by temperature and important to report temperature data along with conductivity values. Conductivity (uS/cm) values can be used to estimate the total concentration of dissolved solids. The Lower Irrawaddy River water quality status in terms of PH, Temperature (^{o}C), Conductivity (µS) and TDS (ppm) results are presented below (Figure 7.7 and Figure 7.8, Appendix B).







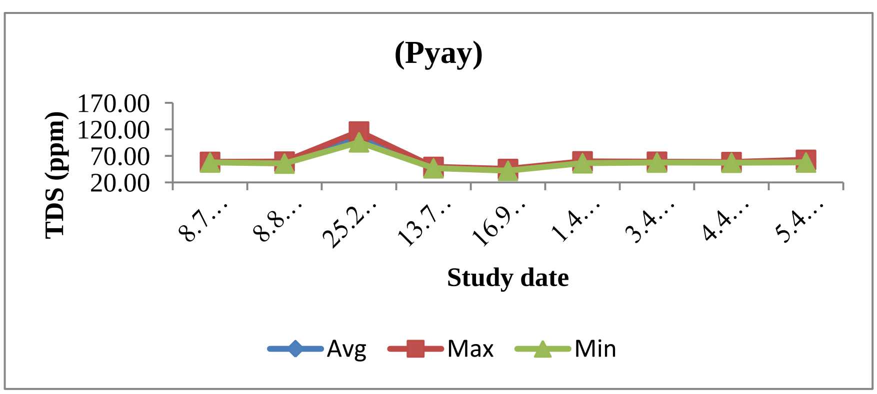


Figure 7.7 Water quality PH, Temperature, Conductivity and TDS variation in Pyay

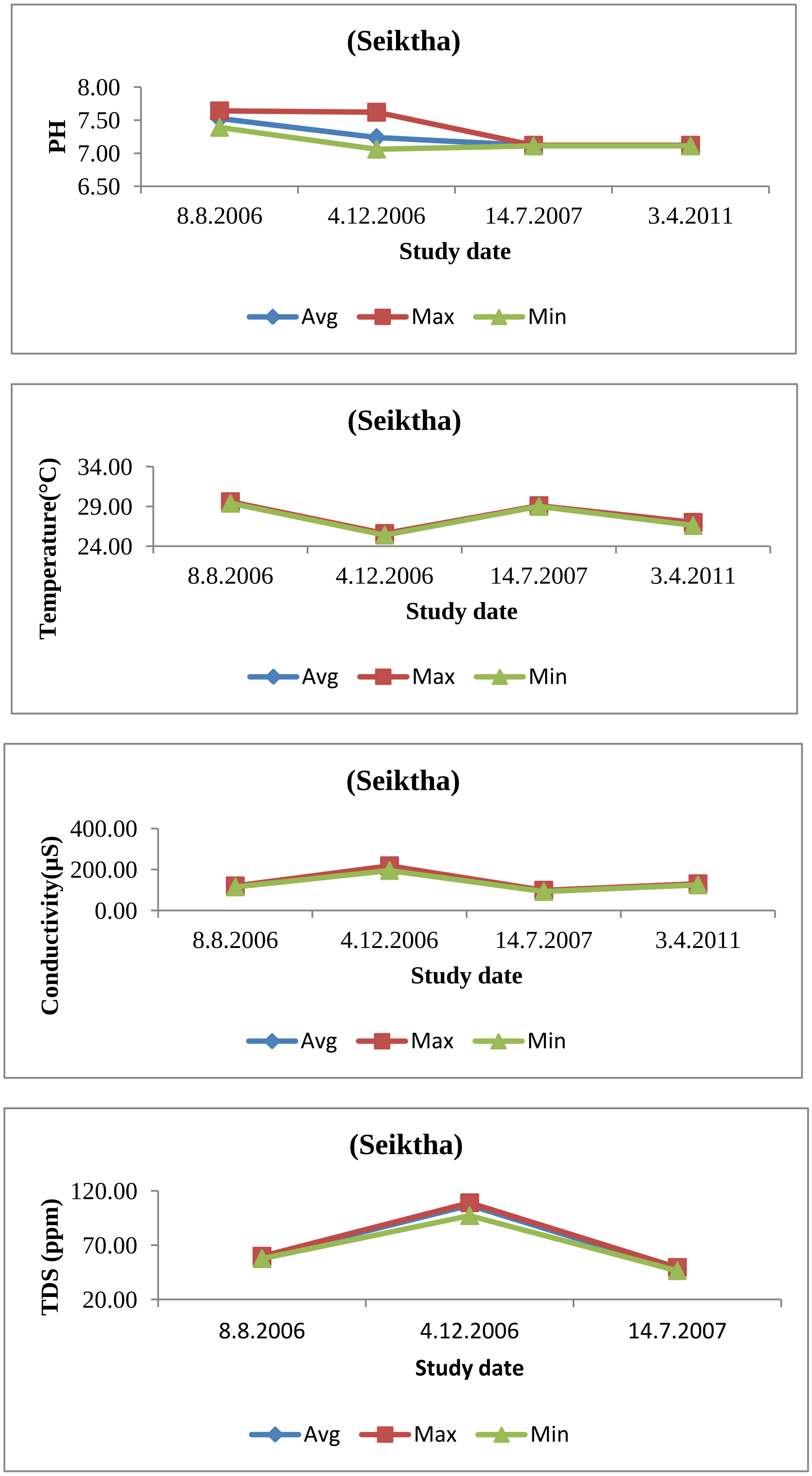


Figure 7.8 Water quality PH, Temperature, Conductivity and TDS variation in Seiktha

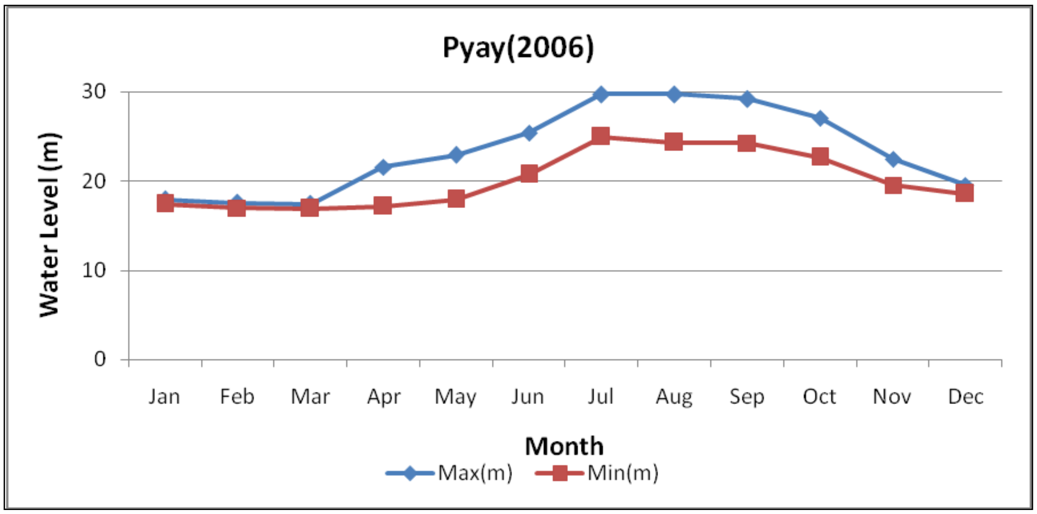
The Irrawaddy River water levels are taken from Pyay gauging station, (Hydrology and Meteorology Department of Myanmar) the monsoon and summer months of maximum water level are shown in (Table 7.2). Figure 7.9 shows the monthly water level of the Lower Irrawaddy River (2006-2007) at Pyay station. SEBA data logger automated measurements of minimum and maximum water level data are shown in Table 7.3 and Appendix D**.** Note that the water level data collected by the international project has not yet been calibrated to the stage record at the Hydrology and Meteorology Department station. The level of suspended solids in the Irrawaddy rivers change rapidly and unpredictably with changing water depths and velocities, requiring a large number of water quality samples to characterize the inherent temporal variability adequately. An alternative approach is the use of turbidity measurements as a surrogate for Total Suspended Sediment concentrations. Both techniques provide a measure of suspended solids levels in the river, but turbidity measurements have the benefit of automated sampling.

Table 7.2 Water level of Pyay Station (2006-2007)

Monthly Water Level of Pyay Station (2006-2007)					
Monsoon Months	2006	2007	Summer Months	2006	2007
May	22.89	22.53	Nov	22.47	20.2
Jun	25.38	24.97	Dec	19.50	19.84
Jul	29.71	28.09	Jan	17.94	18.29
Aug	29.71	28.87	Feb	17.53	18.29
Sep	29.20	27.88	Mar	17.43	18.29
Oct	27.06	24.83	Apr	21.59	18.31
Maximum (m)	29.71	28.87	Maximum (m)	22.47	20.20
Minimum (m)	22.89	22.53	Minimum (m)	17.43	18.29
Average (m)	27.07	26.07	Average (m)	19.55	18.96

Table 7.3 SEBA data logger data of water level in Pyay Station

Date Start to End	Minimum (m)	Maximum (m)	Average (m)
07.08.2006 - 29.08.2006	22.46	25.58	23.82
25.09.2006 - 14.11.2006	19.8	27.37	23.62
14.11.2006 - 31.12.2006	18.13	19.8	18.5
11.03.2007 - 30.06.2007	18.27	24.97	19.73
15.07.2007 - 08.08.2007	24.47	29.13	26.39
12.08.2007 - 07.09.2007	25.61	28.86	26.85
21.09.2007 - 04.12.2007	19.84	29.27	23.73



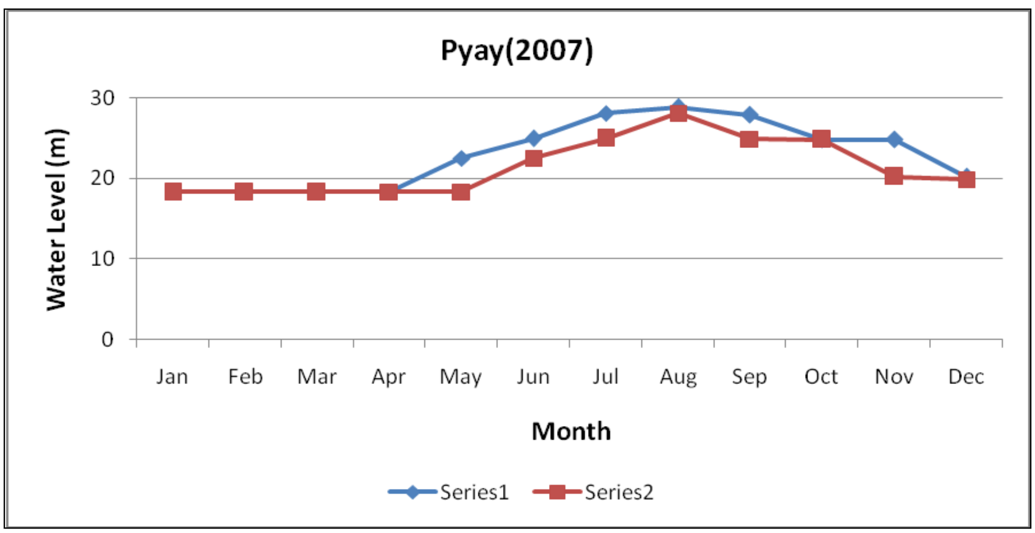


Figure 7.9 Monthly Water level of the Lower Irrawaddy River (2006-2007)

7.5 ADCP measurement result with Sediment concentration

The ADCP discharge data were collected at three study sites. The river discharge during April 2011 is at low dry season levels and the average discharge of at Seiktha was 4461.85 m^3/s and at Pyay was 4038.88 m^3/s (Figure 7.10).

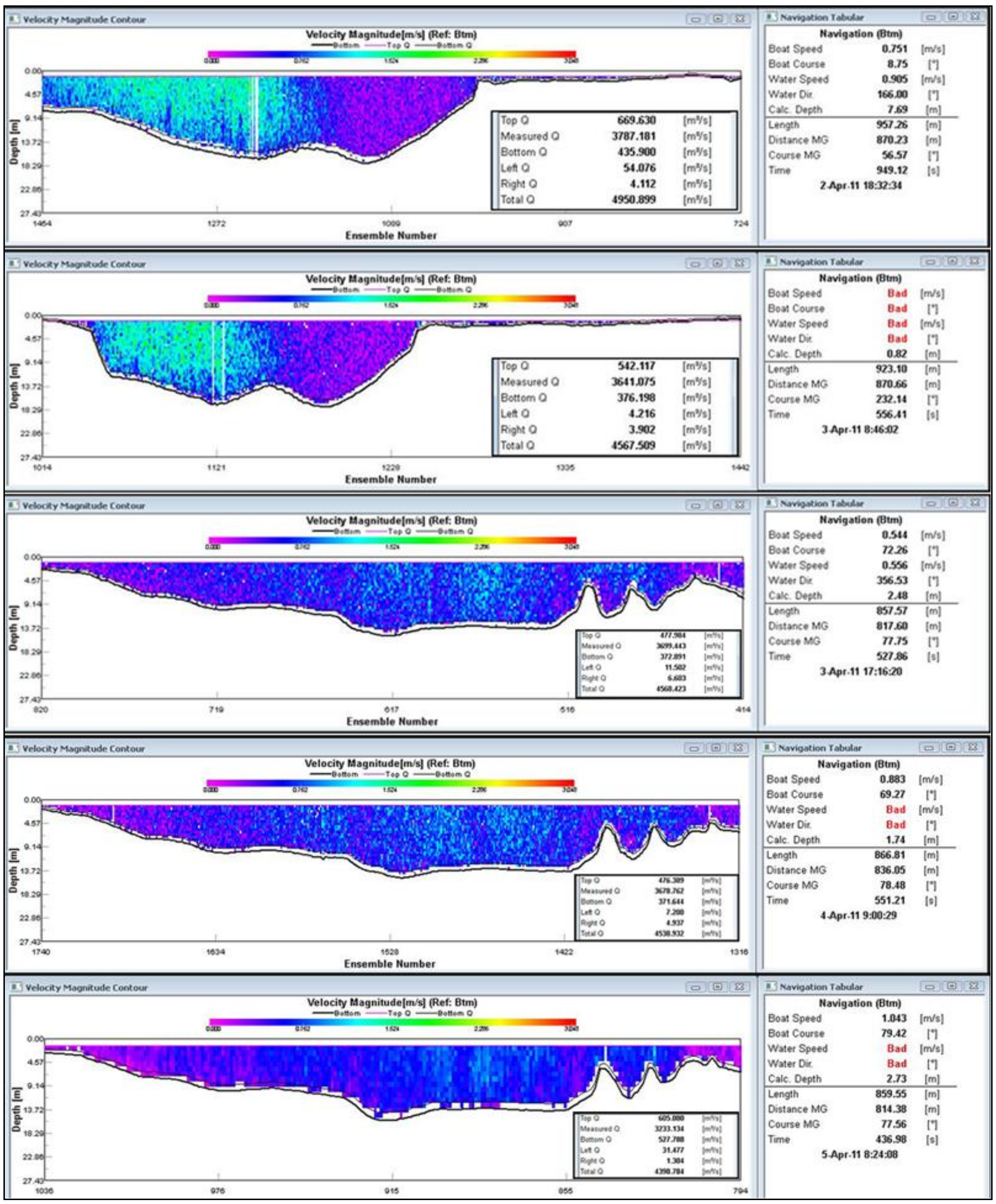


Figure 7.10 River discharge measurement: velocity profile at the study sites

7.6 Suspended Sediment flux calculation

Laboratory analysis of sediment samples of July 2011 was carried out in GeoLab of Department of Geography, National University of Singapore. All samples are weighting with the PG 503-S Delta Range, (Mettler Teledo) Laboratory balance. Total Suspended Solids Dried at 103–105°C in an oven (Plate 7.6) and after cooling in a desiccator were reweighed with lab balance and suspended Sediment concentration (TSS,mg/l) was calculated (Appendix-B).

Plate 7.6 Total suspended solids (TSS) laboratory analysis

Calculation

$$\text{mg total suspended solids/L} = \frac{(A\text{-}B) \times 1000}{\text{Sample volume, mL}}$$

where:

A = weight of filter + dried residue, mg, and
B = weight of filter, mg.

Total Suspended Solids (TSS), is a concentration in mg/l, used to approximate the suspended sediment transported by the river. Suspended sediment load refers to that part of the sediment load carried in suspension by turbulent motion. Sediment discharge and transport rate refer to the mass of sediment passing a stream cross-section in a unit of time (Williams et al, 1989). Unit suspended sediment load is an average area distribution, arrived at by dividing the annual sediment yield by watershed area. A significant amount of suspended sediment data were produced using the total suspended solids (TSS) laboratory analysis method. Annual suspended-sediment flux estimates were calculated using a relation of discharge to suspended-sediment concentration known as a sediment-rating (sediment transport) curve (Horowitz, 2003). The equation to calculate sediment fluxes or loads is the product of discharge, multiplied by suspended-sediment concentration, and multiplied by a conversion factor (Porterfield, 1977; Lewis et al., 2001) to obtain the appropriate mass and time units. The water velocity and the SSC were collected by the ADCP during the transect surveys. The velocity data for each cell or bin from an ensemble was multiplied by SSC values for each corresponding cell that was obtained through the calibration process. The product of the water flux and the concentration at each cell yields the sediment flux through that cell. This process is done throughout the entire profile at which time the values for each ensemble are summed for the entire cross-section. The resultant value is in mg/sec is then converted to tons/day for the cross-section.

Table 7.4 shows ADCP measurement of the average monthly discharge of the Lower Irrawaddy River, Pyay (August, September 2007and April 2011).

Table 7.4 Measured discharge of the lower Irrawaddy River (2007-2011) (in $m^3 sec^{-1}$)

Cross Section	**Aug 2007**	**Sep 2007**	**April 2011**
	Discharge m^3/s		
1	38650.18	34388.84	4725.41
2	38531.44	35494.13	4598.77
3	37723.03	34742.21	4443.52
4	37265.89	34742.21	4538.93
5	36986.67	34742.21	4026.84
6	37693.09	34742.21	3463.20
7	34069.09	30451.09	4309.95
8	35705.05	30451.09	4498.72
Average	37078.05	33719.25	4325.67

The cross-section measurement with ADCP yields an average discharge is 37078m^3/s (August 2007), 33719 m^3/s (Sept 2007) and 4326 m^3/s (April 2011). The discharge data reflect the seasonal variation in rainfall with the peak rainy season in August and September and dry winter season from January to April. The samples taken in April reflect discharge and sediment concentration at relatively low flow conditions.

A maximum concentration value has to be supplied by the profile algorithm to the concentration profile. This value was derived from the actual SSC obtained from the water samples that were collected. The water and sediment sampling period of July, August and December 2006 have been analyzed for the Total suspended sediment (TSS) load range per day from 212 to 405 mg/l at Pyay and from 81 to 502 mg/l at Seiktha (Appendix B). In April 2011, water discharge measurement and water sampling at Pyay and Seikthar of the Irrawaddy River. During the measurement period the maximum depth averaged suspended sediment concentration was 351.11 mg/l and standard deviation was 98.81 mg/l at Pyay. At the study site at Seiktha, the suspended sediment concentration was 416.00 mg/l and standard deviation was 49.71 mg/l (Appendix B).

7.7 Suspended Sediment concentration in study area

Sediment concentration curve is a cumulative distribution function which presents the percentage of time during an average year that a given discharge is equalled or exceeded. A log-log interpolation of the Total Suspended Sediment (TSS) rating curve is used. The flow hydrograph method integrates a hydrograph with a sediment rating curve to evaluate the sediment concentration for a given event. The linear regression scatter of the rating curve suspended sediment concentration (SSC) and discharge Q plotted are for the study sites Seiktha and Pyay (Figure 7.11 and Figure 7.12). The dependency of the mean sediment load on the discharge volume and of the mean SSC from Q was assessed for Pyay and Seiktha. In this study, total average water discharge of Seiktha is 4802.88 m^3/s on 2nd April 2011 and 4520.83 m^3/s on 3rd April 2011, Appendix-B. Total average water discharge of Pyay is 4637.48 m^3/s on 3nd April 2011, 4576.65 m^3/s on 4th April 2011 and 4377.19 m^3/s on 5th April 2011.

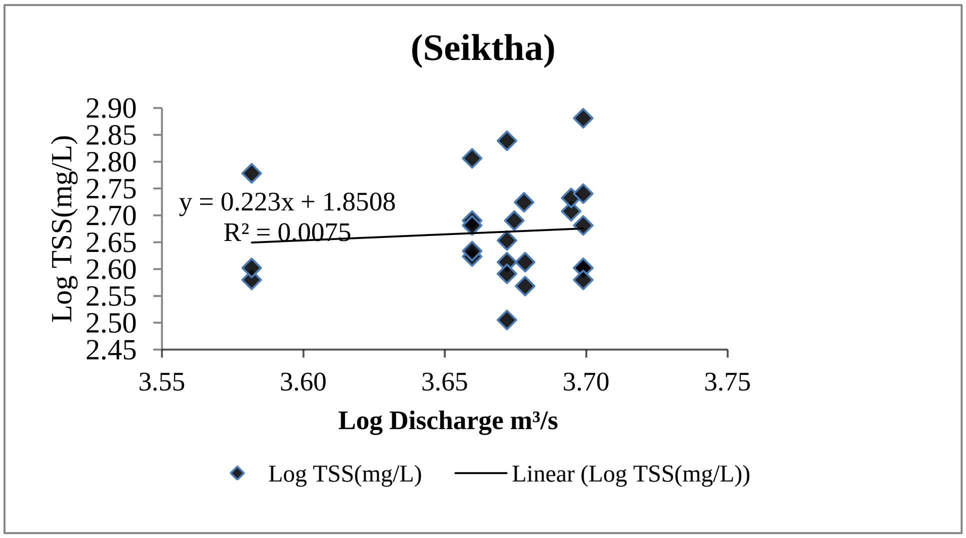


Figure 7. 11 Suspended sediment rating curve for log-linear regression for Seiktha

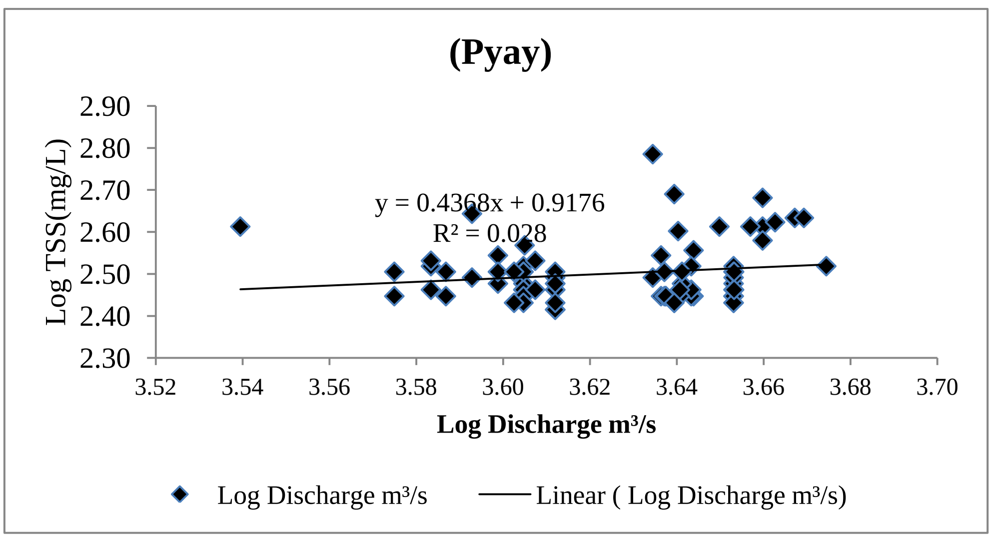


Figure 7.12 Suspended sediment rating curve for log-linear regression for Pyay

7.8 Analysis of sediment particle size

Sediment sampling was conducted during March to April 2011 along the Irrawaddy River. A total of 41 samples was collected from the starting confluence two streams of Irrawaddy River to our study site Seiktha (80 km upstream of the delta) (Plate 7.7**).** Samples were collected from the river bank and GPS point measurements were also made along the Irrawaddy River. Sedimentation particle size measurement depends on the sedimentation rate of the particles in the liquid to measure the particle size distribution. But in fact, it is very difficult to measure the sedimentation rate of the particles. These samples are needed to analyze and describe sediment particle size distribution. The particle size distributions of the suspended sediments are presumed comparable to those of the material, although this particle size analysis has not been conducted-due to lack of time.

Plate 7.7 Sediment samples of the Irrawaddy River

7.9 Summary

In summary, this chapter examined suspended sediment flux and river discharge measurement of the Irrawaddy River at Pyay and Seikthar. In more recent years, sediment input has dramatically increased in Lower Irrawaddy basin areas due to human impacts. The physical impact of soil erosion and sedimentation affects aquatic resources and degrades water quality associated with sediments. Sedimentation in Irrawaddy basin for many years of receiving sediment that accumulated in their turbidity of sediment load during the historical periods of heavy deforestation and lack of soil conservation controls. The estimates of Suspended sediment flux data presented in this study have a comparatively a large uncertainty due to short study period and seasonal change of water discharge and sediment load. The study of 2006, 2007 and 2011 sediment concentration of TSS results are summarized in Appendix B. The different depth of averaged suspended sediment concentration range per day was from 212 to 405 mg/l (2006) and from 270 to 760 mg/l (2011) at Pyay. At the study site at Seiktha, the suspended sediment concentration range per day was 81 to 502 mg/l (2006) and from 380 to 550 mg/l (2011).

The study demonstrates that automatic samplers of ADCP and spot sampling of suspended sediment can be used to develop sediment flux estimates. The accuracy of sediment fluxes can be estimated using sediment rating curves and compared with suspended sediment loads from published studies. The Annual load calculations in this thesis are lower than published values perhaps because of the short sampling time and calculation method. However, results of this applied calibration shows the poor correlation between discharge and total suspended sediment obtained from ADCP. A higher sampling frequency is required to achieve certain level of accuracy and sediment fluxes in large river basin management. Simultaneous measurements were made using a water quality testing and collecting sediment at each site for further geochemical analysis.

8. CONCLUSION

8.1 Summary of main findings and their implication

A brief overview of the study

The large river basins of the world have undergone changes in both climate and human impacts in recent decades. These changes have a wide range of effects on water discharge and sediment flux. Quantifying the sediment budget and hydro-climate change at the basin scale is important for both academic study and river basin management. Sediment budget analysis consists of the evaluation of sediment fluxes, sources and sinks from different processes within catchments. In global river statistics, the Irrawaddy River is fifth largest for suspended sediment load (265MT/year). Recent re-analysis of the sediment load data by Robinson et al. (2007) suggests that this previous figure underestimates the sediment load and that the combined Irrawaddy-Salween River System produces a sediment load of around 600 MT/year). Estimates of sediment budgets can be based on available historical data of Irrawaddy River sediment load and the analysis of changes through empirical or physically-based modelling techniques. Model output can be used to predict the likely budget as a result of some change or development in the system. It is well known that there is a complex interaction among climate, land use and land cover change, soil erosion and sediment loads in the basin. There are different topographic conditions and climate patterns in the large Irrawaddy basin. The greater part of the sediment might be produced in the upper basin and some of the sediment deposited into floodplain stores in the lower basin. The Irrawaddy basin may has experienced change in climate and human activity, which has impacted on water discharge and sediment fluxes. The impact of climate and human activities on sediment dynamic in the Upper Irrawaddy basin is for further study. This study has investigated the impacts of soil erosion form land use/cover change on water discharge and sediment flux and modeling for the Thornes erosion model tools to predict sediment dynamics in Lower Irrawaddy basin. However, there is limited information available regarding the effect of land use and land cover change on the sediment loads. Human activities have resulted in rapid and extensive land cover change in the lower Irrawaddy basin.

Land use/cover change and hydrological change in the Lower Irrawaddy basin

Land cover refers to the major classification of the use of the different parcels of land in the holdings in study area. The technologies of GIS/ RS have been combined to detect and control to land cover changes and which is easier and faster than the traditional methods of surveying to the natural environment. Supervised classification and maximum likelihood procedures were implemented to classify the Landsat images into the established land use and land cover classification for the Lower Irrawaddy basin. In this study basin**,** the land cover types were forest land, agricultural land, barren land and floodplain vegetation area. They accounted for approximately 90% of the basin, urban land covers were not included classified in this study. Most of the urban area was located along the Irrawaddy River bank and rural villages are adjacent to agricultural land. Water is the smallest land cover category accounting for less than 3%. Different land cover type showed different trends of change during time periods of 1989-2010. Forest type land cover was decreased by approximately 50 % during this study period of twenty one years. According to the Central Statistical Organization of Myanmar, the total forest area in Myanmar decreased from 56% of the total land area in 1990 to 50.2% in 2005.Agricultural land cover has gradually increased and through increases in population and food production, intensive cultivation and agricultural land resources developed during the period. The total area of all barren land in the study area has also changed probably because of extension of the settlement area and land for economic development. The floodplain vegetation area is partly wetland and partly used for agriculture and fish ponds. The change of floodplain vegetation was not as significant as for other land covers.

The spatial distribution of the land use/cover types in the Lower Irrawaddy basin showed the actual influences of human activity and the environment. However, there are different types of land use/land cover definition and classification methods, e.g. satellite image classification with different standards used for land use classification. Existing land use/land cover maps, ground truth data and the documentation of land use time series have to be compared in order to assess actual land use change. More detailed land use/land cover data may help to improve the understanding of impacts within the Lower Irrawaddy basin study. Physical changes of land use/cover influence hydro-climatic conditions and the runoff process in the Lower Irrawaddy basin. The changes of water, forest land, agricultural land, barren land and floodplain vegetation area result in hydrological change in the basin. These land use/cover change patterns showed the strong influence of human activities in the lower Irrawaddy basin.

Hydro-climatic conditions in the Lower Irrawaddy basin

Annual rainfall in the Lower Irrawaddy is strongly influenced by the tropical monsoon. Between 1985 and 2005, the lowest annual rainfall was 795 mm in 1998 and the highest annual rainfall was1605 mm in 2005. Analysis of the daily rainfall 1985 to 2005 at Pyay Station is representative of the Lower Irrawaddy basin. The analysis of rainfall data is vital to understanding of hydro-climate of the basin. Comprehensive statistical analysis is also employed in the frequency analysis of precipitation and rainfall fluctuation. The rainfall may reflect the influence of El Niño and La Niña events. This has naturally led to a lot of concern and the southwest monsoon about the causes. It can be seen clearly that the shortfall in rainfall is a part of the natural variability. Analysis of the statistical rainfall result show that no rain days is 2163, rainfall less than 25 mm is 1901 days and rainfall above 25 mm is 326 days in study period of 1989 to 2005. Generally, forecasts for seasonal rainfall are generated, whether other climate factors of event could have been foreseen, and the perspective on the problems and prospects of forecasting the summer monsoon rainfall over basin. The seasonal rainfall is support to a physically base climate impact on erosion runoff and river behavior to study in area.

The annual water discharge and sediment flux and rainfall in the Irrawaddy basin showed a significant increase from the nineteenth century to the study period of 2010s.Anoriginal 19^{th} Century dataset by Gordon (1885) calculates suspended sediment load as 261MT/year. The original 19th century data underestimated the actual sediment load. Robinson et al. (2007) suggest the sediment load is $364 \pm 60 \times 10^6$ t/year. A more recent study of discharge and suspended sediment load by Furuichi et al. (2009) calculates a sediment load of 325 ± 57x10^6 t/year. In 2005 and 2006, the field measurement of discharge and collection of sediment data was undertaken .The results from the field measurement were compared with the original 19th Century data produced by Gorgon. Robinson et al. (2007) have re analyzed the original data and concluded that the 10-yr average of water flux for the Irrawaddy River at Seiktha was 41153 km^3yr, transporting 266-334 MT of suspended load. More than 90% of the annual sediment load is delivered during the monsoon between mid- June and mid-November. The annual maximum total suspended sediment at Pyay showed an approximately 350 ± 60 x 10^6 t/year (1966 to 1996). In this study of suspended sediment flux measured in April 2011.As these measurements are based on dry season discharge and suspended sediment concentration they are obviously much lower than wet season sediment loads. The estimates of suspended sediment flux presented in this study have a comparatively large uncertainty due to the short study period and seasonal changes of water discharge and sediment load. However, this result is representative a part of the continuous research for the suspended sediment load in Irrawaddy River. The suspended sediment concentration range per day was from 212 to 405 mg/l (2006) and from 270 to 760 mg/l (2011) at Pyay 81 to 502 mg/l (2006) and from 380 to 550 mg/l (2011) at Seiktha of the Irrawaddy River. The suspended sediment concentration is different ranges in the dry season and wet season. The study of Irrawaddy River suspended sediment concentration and discharge has to be continuous monitoring for further research. Therefore, the changes of water discharge and suspended sediment flux at Lower Irrawaddy basin was showed the result of climate impact and indirect effect of human activities.

Soil erosion modelling and SCS- CN runoff in the lower Irrawaddy basin

The Soil Conservation Service (SCS) - Curve Number (CN) method was employed to simulate the characteristics of surface runoff at the Lower Irrawaddy basin, which depend in turn upon the rainfall, runoff and infiltration coefficients calculated for each sub-basin. The results show the effect of soil types, land use/land cover, vegetation densities and basin morphometric parameters on the spatial distribution of the surface runoff. As input data for the rainfall-runoff model, this study selected five rainfall stations of the study area. ArcGIS and Spatial Analysis of ArcHydro supply efficient and straight forward method to compute Hydrologic parameters which have spatial characteristic of raster data for Hydrologic computing in study basin. To reflect spatial rainfall characteristics of precipitation data of specific hydrologic events, the Thiessen weight method was used. Finally, results of runoff for the Lower Irrawaddy basin were estimated. In this study the result only represents estimated Rainfall-runoff. In chapter six the rate of soil erosion for the Lower Irrawaddy basin was estimated by using a geographic physically based model developed by Thornes (1985,1989) given by $E= kQ^2 * S^{1.67} *e^{(-0.07 *v)}$. where, (E) is erosion in mm/month, and the percentage of vegetation cover (v), Slope(S) and coefficient of soil erodibility (k). The parameter Q is overland flow (mm) on annual basis obtained from runoff coefficient. Soil erodibility factor K value is 0.04 to 0.3 and the annual runoff is 759.01 to 1569.2 mm found in the lower Irrawaddy basin. Slope (S) factor of slope degree is 0 to 22 and the slope tangent value is 0 to 0.4 in the study area. The vegetation cover (v) cover percentage is 0.0009 to 0.6158 for the calculation of soil erosion. These steps of watershed delineation, runoff estimation and vegetation cover were the principal steps for calculating Thornes soil erosion model for the Lower

Irrawaddy basin. The regional scale erosion model has been the limited validation of Thornes model parameters as well as outputs of the erosion rates. The erosion model was applied at 1km spatial scale resolution and calculating with ArcGIS spatial analyst. The spatial patterns of predicted maximum annual erosion rate observed 0.0 to 21.0 mm/year in the lower Irrawaddy basin. The result is reasonable for the annual erosion rates but it towards overestimation. Throughout the erosion modelling has been generated and there have some of the limitations of hydrological factor analysis. However this study presented low data requirements and base on the physiographic characteristic of large scale drainage basin scale distributed annual erosion rates. This rainfall runoff and soil erosion rates can be extended further to assess could be useful for other basin planning of various management and conservations.

Water discharge and Total Suspended Sediment (TSS)

For water analysis, 108 water samples (1Litre bottles) were collected with a horizontal 2 L Van Dorn sampler. At three sites along the lower Irrawaddy, where cross-section and discharge measurement was made with ADCP. The temperature, conductivity, and pH of each sample were determined on site. Average of each water parameter is temperature 29.29 °C, pH 7.12 and Conductivity 117.59(μs). Average water discharge of Seiktha was 4802.88 m^3/s and Pyay was 4637.48 m^3/s. Suspended Sediment (SSC) at Seiktha was 517.33 (mg/L) and at Pyay was 366.67 (mg/L) in the study period of April 2011.

In summary, this study tried to improve the short-term predictions of suspended sediment concentration in the Lower Irrawaddy basin by using Thornes erosion model and suspended sediment flux conditions at the Lower Irrawaddy river of Pyay and Seiktha. However, river data gathered are too few and the erosion model data involve too many assumptions to enable wider conclusions to be drawn. Thus, if this Thornes model were to improve for predictions of sediment dynamics in future study, there are several factors be considered:

1. using more detailed observational time series data for different stations in the whole Irrawaddy basin so that the lower Irrawaddy basin contribution can be separated;
2. considering with ADCP differences river channel discharge and suspended sediment load;
3. getting more spatial coverage and a longer period of data at river sediment flux at upper Irrawaddy basin; especially along the river channel of main tributary and streams;
4. examining the actual land use /cover change and soil erosion within the whole basin area need to combining with GIS/RS; and
5. if the detail concern of the monthly averaged predictions of suspended sediment flux may be the constant of Thornes erosion model is good enough and predicting sediment dynamics in the Lower Irrawaddy basin .

8.1.1 Limitation of study

GIS-based computing models provide hydrologist and planners with important tools, which is able to view data spatially. In this study, GIS/ RS prove to be an indispensable tool in aiding the assessment of soil erosion and sediment delivery in Lower Irrawaddy basin. With the improvement suggested above, GIS will provide even more comprehensive analysis. This study has tried to address the river discharge and sediment flux with a methodological framework to constructing sediment budget and sediment delivery of source to sink processes for large scale drainage basin of the Lower Irrawaddy basin. However, some of the limitations need to be addressed in future studies.

Firstly, future studies should sample from more than three depths in order to quantify suspended sediment transport more accurately. This is important in the determination of both suspended sediment flux and sediment geochemical analysis study. Sampling is only a small fraction of the water column and especially during extreme events, may misrepresent depth averaged suspended sediment concentrations. Secondly, water discharge and suspended sediment flux need to monitorial through the seasons in study area at a series of stations along the lower Irrawaddy. Thirdly, for reliability of predictions sediment dynamics in the large scale basin needs to examine the influence of soil erosion and sediment transportation with modelling and field observation. Furthermore, the quantitative result of daily, monthly and annually sediment load data is required to evaluate their accuracy.

8.1.2 Prospects and future work

The Irrawaddy River basin has been affected by severe soil erosion which contributes to a high sediment load. Several issues related to the development of large rivers remain unresolved. An improved understanding of spatially variable sediment flux source to sink and sediment budgets provide a platform to analyze the impacts of environmental changes. The study of sediment budget analysis in the Irrawaddy basin in Myanmar remains a great challenge. Especially, for this research field work investigation it was very difficult to get permission and the upper Irrawaddy River transportation routes are unsafe under present conditions. Future work, which not possible in timeframe of the thesis includes geochemistry and particle size analysis of the sediments collected during fieldwork.

8.2 Conclusion

The availability of global environmental datasets in combination with GIS and remote sensing techniques provides an opportunity for identifying and measuring potential sediment source areas and quantifying their respective contributions in large basins. The creation of a sediment budget is an approximate balance that can be carried out on local or regional scales. The relative importance of the dominant suspended sediment flux can be assessed at any or all of these scales depending on the characteristics of the study area. The regional scale study method is highly dependent on modeling and the overland flow, slope erosion from different land use to Thornes model estimates thorough understanding of the historical changes in river discharge and suspended sediment flux suspension. It is very important to understand the uncertainty inherent in the development of a sediment budget, as the conclusions may sometimes depend on spatial and temporal scale study.

This current research has provided a better understanding of human activities of land use/cover changes and climate impacts of rainfall runoff and soil erosion in the Lower Irrawaddy basin. A field study measurement of for water discharge measurements and water sampling and total Suspended Sediment (TSS) concentration in Lower Irrawaddy River. In addition, this finding will be useful for river basin management and environmental studies.

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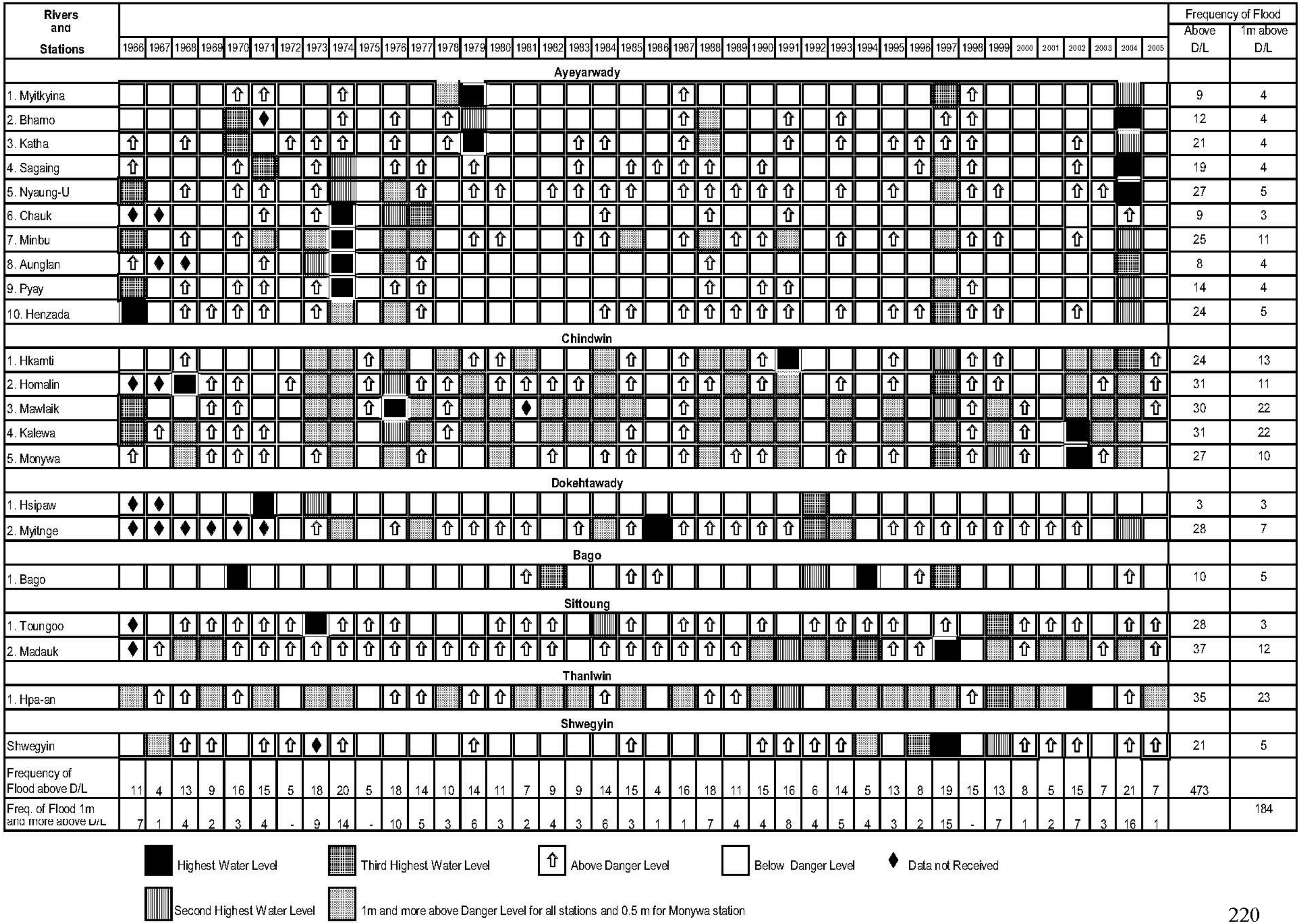
APPENDIX A

Annual Maximum Water level for Major Rivers at Different Stations in Myanmar From 1966 to 2005



APPENDIX B

Temperature/pH/Conductivity/TDS/TSS (PYAY)									
Date	Time	Location	depth	Turbidity	Temp	pH	conductivity	tds	sediment
8.7.2006	am		(m)	(FTU)	(°C)		(μS)	(ppm)	(mg/l)
	11:30	Site 1	45			7.72	115.30	57.90	
			23			7.70	115.00	57.70	366
			1			7.69	115.80	58.00	354
	14:30	Site 2	10			7.67	115.60	58.50	359
			5			7.66	117.90	58.70	398
			1			7.64	117.40	58.70	396
	15:00	Site 3	43			7.62	115.90	57.70	317
			21.5			7.57	115.40	57.80	398
			1			7.25	116.10	57.80	373
		average				7.61	116.0	58.1	405
		SD				0.14	1.0	0.4	108

Date	Time	Location	depth	Turbidity	Temp	pH	conductivity	tds	sediment
8.8.2006	am		(m)	(FTU)	(°C)		(μS)	(ppm)	(mg/l)
		Site 1	56		30	7.13	115.1	55.7	250
			28		30	7.17	116.2	58.1	212
			1		30.1	7.43	117.8	58.8	329
		Site 2	47		30	7.16	115	57.7	299
			28.5		30	7.38	115.4	57.6	239
			1		30.1	7.41	117.8	58.9	321
		Site 3	5		30.1	7.24	118.7	59.2	347
			2.5		30.1	7.51	118.4	59.2	321
			1		30.1	7.56	115	57	292
		average			30.06	7.33	116.6	58.0	290
		SD			0.05	0.16	1.6	1.2	46

Date	Time	Location	depth	Turbidity	Temp	pH	conductivity	tds	sediment
25.2.2007	pm		(m)	(FTU)	(°C)		(μS)	(ppm)	(mg/l)
		Site 1	26	42.9	25.5	7.12	218	108	
			13	47.8	25.1	7.12	218	108	
			1	44.1	25	7.12	195.9	99.7	
		Site 2	26	44.3	25.7	7.11	199.9	108	
			13	42.1	25.4	7.11	199.2	108	
			1	40.8	25.2	7.11	217	116	
		Site 3	15	37.4	25.6	7.12	190.3	95.8	
			7.5	39.9	25.8	7.12	198.9	98.9	
			1	31.2	26.3	7.12	194	97.2	
		average		41	25.5	7.12	203.5	104	
		SD		5	0.4	0.00	11.1	7	

Date	Time	Location	depth	Turbidity	Temp	pH	conductivity	tds	sediment
13.07.07	am		(m)	(FTU)	(°C)		(µS)	(ppm)	(mg/l)
		Site 1	4		29.1	7	96.2	48.3	
			1		28.9	7.14	98.6	49.2	
		Site 2	35		29	7.14	94.8	47.3	
			17		29.3	7.36	95.1	47.4	
			1		29.1	7.22	95.3	47.5	
		Site 3	25		29.1	7.18	95.6	47.8	
			14		28.9	7.22	97.5	48.7	
			1		28.7	7.27	95.4	47	
		Site 4	25		28.8	7.15	93.8	46.8	
			13		28.9	7.22	93.4	46.7	
			1		29	7.27	96.8	48.4	
		average			29.0	7.20	95.7	48	
		SD			0.2	0.09	1.5	1	

Date	Time	Location	depth	Turbidity	Temp	pH	conductivity	tds	sediment
16.09.2007	10:30		(m)	(FTU)	(°C)		(µS)	(ppm)	(mg/l)
		Site 1	7		29.8	6.95	90.3	45.3	
			3.5		29.7	7.14	84.2	42.4	
		Site 2	15		29.9	7.09	88.6	44.8	
			9		29.9	7.18	84.6	42.8	
			1		29.6	7.36	84.8	42.4	
		Site 3	46		29.8	7.18	83.5	42.5	
			23		29.5	7.36	83	42	
			1		29.6	7.26	87.5	44.3	
		Site 4	48		29.6	7.35	83.6	42.3	
			24		29.3	7.31	82.8	41.5	
			1		29.4	7.35	85.2	42.7	
		average			29.6	7.23	85.3	43	
		SD			0.2	0.13	2.5	1	

Date	Time	Location	depth	Turbidity	Temp	pH	conductivity	tds	sediment
1.4.2011	6:15	Site 1	(m)	(FTU)	(°C)		(µS)	(ppm)	(mg/l)
			17.50		16.90	7.53	139.80	18.30	690
			8.50		21.30	7.43	142.00	18.70	640
			1.00		28.10	7.13	141.40	18.70	480
	5:50	Site 2	29.00		28.70	7.12	145.70	18.70	530
			14.50		28.70	7.65	142.10	17.40	540
			1.00		17.20	7.30	141.10	17.89	490
	6:40	Site 3	8.50		28.10	7.68	140.10	18.10	760
			4.00		28.30	7.60	133.80	17.96	480
			1.00		28.30	7.31	137.20	18.30	450
		average			25.1	7.42	140.4	18	562
		SD			5.1	0.21	3.3	0	109

Date	Time	Location	depth	Turbidity	Temp	pH	conductivity	tds	sediment
3/4/2011	pm		(m)	(FTU)	(°C)		(µS)	(ppm)	(mg/l)
	5.48	Site 1	9.00		27.20	7.86	120.20		410
			4.00		27.20	7.81	120.60		400
			1.00		27.30	7.90	122.30		430
	5.55	Site 2	14.00		27.20	7.68	119.20		480
			7.00		27.10	7.69	118.10		420
			1.00		27.20	7.68	118.40		380
	0:00	Site 3	7.00		28.00	8.25	120.80		430
			4.00		27.40	7.99	120.00		410
			1.00		27.20	7.68	119.80		330
		average			27.3	7.84	119.9		410
		SD			0.3	0.19	1.3		41

Date	Time	Location	depth	Turbidity	Temp	pH	conductivity	tds	sediment
4.4.2011	am		(m)	(FTU)	(°C)		(µS)	(ppm)	(mg/l)
	11:38	Site 1	15.00		27.30	7.12	119.70		310
			12.00		33.50	6.87	121.20		410
			9.00		30.20	6.78	113.10		370
			4.50		28.80	6.78	114.20		300
			1.00		32.90	6.74	112.60		310
	10:25	Site 2	30.00		34.40	7.25	109.80		290
			15.00		32.20	7.13	28.60		410
			1.00		34.00	7.08	112.90		280
	9:33	Site 3	14.00		31.50	6.50	117.70		290
			7.00		31.80	6.50	116.60		300
			1.00		30.60	6.59	119.60		270
			12.00		27.60	6.42	55.40		300
			6.00		39.50	7.03	59.90		290
			1.00		28.90	6.66	115.50		280
			7.00		26.10	6.28	110.20		290
			3.50		34.10	6.50	117.00		280
			1.00		30.20	6.60	115.10		290
			12.00		35.90	7.11	116.30		610
			12.00		35.90	7.11	116.30		320
			6.00		32.50	6.52	126.80		330
		average			31.9	6.78	105.9		327
		SD			3.3	0.29	25.9		78

Date	Time	Location	depth	Turbidity	Temp	pH	conductivity	tds	sediment
4.4.2011	pm		(m)	(FTU)	(°C)		(µS)	(ppm)	(mg/l)
	4:30	Site 1	18		27.00	7.12	116.70	58.30	300
			9		26.40	7.12	115.70	57.80	320
			1		27.20	7.12	116.10	57.90	330
			1		28.50	7.81	113.40	57.60	290
	3:50	Site 2	35		27.00	7.10	115.10	57.60	320
			17		27.00	7.11	115.70	57.80	270
			11		28.00	7.50	114.40	57.70	290
			7		24.40	7.54	114.90	57.70	300
			1		28.00	7.63	115.10	57.30	280
			10		28.90	7.64	115.90	58.00	270
			5		27.90	7.72	114.30	56.80	280
			1		28.10	7.74	117.30	58.50	260
	4:00	Site 3	30		27.10	7.11	116.80	58.40	290
			15		27.30	7.12	119.70	59.70	310
			5		28.50	7.18	111.60	56.30	270
			2.5		27.40	7.20	118.10	58.40	320
			1		28.00	7.56	118.00	58.20	320
		average			27.5	7.37	115.8	58	295
		SD			1.0	0.27	1.9	1	22

Date	Time	Location	depth	Turbidity	Temp	pH	conductivity	tds	sediment
5.4.2011	am		(m)	(FTU)	(°C)		(µS)	(ppm)	(mg/l)
	9:57	Site 1	18.00		28.20	7.12	116.10	58.60	320.00
			9.00		28.20	7.12	112.19	61.10	310.00
			1.00		28.70	7.12	118.00	59.30	330.00
			13.00		27.10	7.11	117.30	58.50	350.00
			6.50		26.70	7.12	115.40	57.70	350.00
			1.00		26.70	7.12	115.30	57.80	340.00
	10:05	Site 2	35.00		28.40	7.12	125.10	62.50	280.00
			17.50		28.80	7.12	117.00	58.30	280.00
			9.00		26.70	7.12	116.00	57.90	320.00
			1.00		28.00	7.11	116.30	57.90	290.00
	10:15	Site 3	14.00		27.90	7.11	117.30	58.80	280.00
			7.00		27.80	7.11	120.80	60.10	290.00
			1.00		28.50	7.11	118.70	59.60	280.00
			4.50		26.70	7.12	115.40	57.70	300.00
			1.00		26.80	7.12	116.90	58.10	290.00
			4.00		26.80	7.12	118.10	59.10	320.00
			1.00		26.70	7.12	117.80	58.90	360.00
		average			28	7	117	59	311
		SD			1	0	3	1	28

Date	Time	Location	depth	Turbidity	Temp	pH	conductivity	tds	sediment
5.4.2011	pm		(m)	(FTU)	(°C)		(μS)	(ppm)	(mg/l)
	4:20	Site 1	25.00		28.70	7.12	116.60	58.20	340.00
			12.50		29.10	7.11	116.30	58.10	270.00
			1.00		28.50	7.12	118.30	59.00	320.00
			14.00		29.30	7.12	118.20	59.00	280.00
			7.00		29.40	7.11	117.10	58.50	290.00
			1.00		29.50	7.11	118.10	59.00	270.00
	3:45	Site 2	35.00		28.60	7.12	115.20	57.60	490.00
			17.00		28.80	7.12	115.40	57.70	280.00
			1.00		29.70	7.11	116.40	58.20	320.00
			13.00		29.70	7.11	117.50	58.70	280.00
			6.50		29.60	7.12	117.70	58.70	280.00
			1.00		29.30	7.12	118.70	59.30	320.00
	4:05	Site 3	20.00		29.70	7.11	119.60	59.70	330.00
			10.00		29.10	7.12	118.10	59.10	320.00
			1.00		29.30	7.12	118.40	59.10	280.00
			6.00		29.60	7.11	118.70	59.20	290.00
			3.00		29.60	7.11	118.00	59.00	300.00
			1.00		29.70	7.11	118.40	59.30	270.00
		average			29	7	118	59	307
		SD			0	0	1	1	51

SEIKTHA

Temperature/pH/Conductivity/TDS/TSS(SEIKTHA)									
			depth	Turbidity	Temp	pH	conductivity	tds	sediment
Date	Time	Location	(m)	(FTU)	(°C)		(μS)	(ppm)	(mg/l)
8.8.2006	13:00	Site 1	25		29.60	7.39	118.80	59.20	478
			13		29.50	7.52	118.10	58.90	469
			1		29.60	7.63	118.40	59.10	450
	13:15	Site 2	16		29.50	7.51	116.80	58.20	502
			8		29.40	7.50	115.00	57.60	495
			1		29.50	7.59	118.10	59.00	436
	13:30	Site 3	23		29.40	7.42	119.30	59.80	478
			12		29.40	7.52	118.50	59.40	471
			1		29.50	7.64	119.70	59.80	487
		average			29.49	7.52	118.1	59.0	474
		SD			0.08	0.09	1.4	0.7	21

			depth	Turbidity	Temp	pH	conductivity	tds	sediment
		Location	(m)	(FTU)	(°C)		(µS)	(ppm)	(mg/l)
Date	Time	Site 1	22	155.5	25.4	7.23	194.8	107	89
4.12.2006	pm		10	141.1	25.5	7.07	216	108	81
			1	125.4	25.4	7.23	199	97.2	90
		Site 2	12	178.0	25.4	7.06	218	109	
			7	137.5	25.4	7.24	215	107	82
			1	151.8	25.4	7.62	215	109	87
		Site 3	14	135.1	25.6	7.1	217	108	68
			7	122.7	25.5	7.33	217	108	87
			1	144.0	25.6	7.25	216	108	84
		average		143	25.5	7.24	212.0	107	113.94
SD		SD		17	0.1	0.17	8.7	4	83.18

Date	Time	Location	depth	Turbidity	Temp	pH	conductivity	tds	sediment
14.07.2007		Site 1	(m)	(FTU)	(°C)		(µS)	(ppm)	(mg/l)
			15		29.1	7.12	98.8	49.4	
			8		29.1	7.12	96.1	48	
		Site 2	1		29	7.12	95.8	47.9	
			25		29.1	7.12	94.9	47.4	
			12		29.1	7.12	95.9	48	
		Site 3	1		29	7.11	96.5	48.1	
			14		29.1	7.12	94	46.5	
			7		29.1	7.11	92.9	46.7	
		Site 4	1		29.1	7.12	93.6	46.7	
			4		29.2	7.12	94.3	47.1	
			1		29.1	7.11	96.5	48.1	
		average			29.09	7.12	95.39	47.63	
		SD			0.05	0.00	1.67	0.85	

Date	Time	Location	depth	Turbidity	Temp	pH	conductivity	tds	sediment
3.4.2011	am		(m)	(FTU)	(°C)		(µS)	(ppm)	(mg/l)
	7:20	Site 1	9.00		26.60	6.83	129.90		420
			4.50		26.70	7.35	128.60		400
			1.00		26.70	7.09	124.80		380
	7:35	Site 2	18.00		26.60	6.83	129.90		420
			9.00		26.70	7.35	128.60		400
			1.00		26.80	7.47	129.30		550
	8.00	Site 3	8.00		26.60	6.85	130.10		400
			4.00		27.00	6.83	129.30		410
			1.00		26.90	7.12	130.30		390
		average			26.7	7.08	129.0		419
		SD			0.1	0.26	1.7		51

Sample of SEBA automated measurement of water depth data

W.A.S.GmbH		data evaluation in ASCII-Format		
serialno./SW-Vers..........:	F33010/5.26			
File name...................:	C:\SEBA\WBEDIEN32\Daten\			
evaluation	with............:	wBedien	1.36	
evaluation	from............:	4-Dec-07	8:46:39	AM
free	text	for	station......:	Myanmar-Pyay
free	text	for	channel......:	
No.	of	values..............:	1889	
start	of	measurement.......:	Date	Time
end	of	measurement.........:	Date	Time
Date/Time	Value			
				Depth(m)
minimum	on	29.08.2006	5:05:00	22.46
maximum	on	07.08.2006	14:05:00	25.58
	average	value:	23.82	
minimum	on	14.11.2006	8:16:56	19.8
maximum	on	25.09.2006	17:16:56	27.37
	average	value:	23.62	
minimum	on	31.12.2006	18:20:53	18.13
maximum	on	14.11.2006	9:20:53	19.8
	average	value:	18.5	
minimum	on	11.03.2007	7:20:53	18.27
maximum	on	30.06.2007	7:20:53	24.97
	average	value:	19.73	
minimum	on	15.07.2007	2:45:45	24.47
maximum	on	08.08.2007	3:45:45	29.13
	average	value:	26.39	
minimum	on	07.09.2007	3:50:49	25.61
maximum	on	12.08.2007	10:50:49	28.86
	average	value:	26.85	
minimum	on	04.12.2007	6:56:18	19.84
maximum	on	21.09.2007	22:56:18	29.27
	average	value:	23.73	

APPENDIX C

ADCP Discharge data (2007 - 2011)

File Name(PYAY)	Total Q [m³/s]	Left Q [m³/s]	Top Q [m³/s]	Meas. Q [m³/s]	Bottom Q [m³/s]	Right Q [m³/s]	Total Area [m²]	Width [m]	Depth Ref.
DATA_002r.000	38650.18	43.702	2405.27	33353.19	2841.7	6.322	19924.1	1270.7	ADCP
DATA_003r.000	38531.44	45.97	2280.878	33694.18	2506.654	3.756	20632.36	1246.32	ADCP
DATA_004r.000	37723.03	2.029	2199.601	33006.35	2502.581	12.467	21325.48	1287.67	ADCP
DATA_005r.000	37265.89	47.517	2378.076	32336.09	2498.991	5.211	20050.2	1321.81	ADCP
DATA_20070811152154_000r.000	36986.67	77.944	2968.972	30006.63	3917.845	15.281	18268.61	997.89	ADCP
DATA_20070811154358_000r.000	37693.09	51.262	2235.891	31940.01	3443.792	22.128	21218.64	1022.18	ADCP
DATA_20070811160200_000r.000	34069.09	85.919	2085.693	29465.86	2429.354	2.256	26023.91	1089.47	ADCP
DATA_20070811162020_000r.000	36705.05	26.727	2145.185	30708.2	3788.07	36.868	21781.35	1016.79	ADCP
Average	37203.05	47.634	2337.446	31813.82	2991.123	13.036	21153.08	1156.6	
Std. Dev.	1438.741	26.546	277.214	1586.437	627.049	11.739	2251.09	137.76	
Std./| Avg.|	0.04	0.56	0.12	0.05	0.21	0.9	0.11	0.12	

File Name(PYAY)	Total Q [m^3/s]	Left Q [m^3/s]	Top Q [m^3/s]	Meas. Q [m^3/s]	Bottom Q [m^3/s]	Right Q [m^3/s]	Total Area [m^2]	Width [m]	Depth Ref.
DATA_20070916103742_000r.000	34388.84	19.738	2732.993	29369.27	2273.094	-6.255	20062.69	1283.82	ADCP
DATA_20070916111322_000r.000	34594.13	0.841	2677.421	29536.53	2377.165	2.172	20786.01	1316.59	ADCP
DATA_20070916113050_000r.000	34742.21	41.854	2753.089	29594.75	2352.436	0.075	20001.83	1294.17	ADCP
DATA_20070916115051_000r.000	35132.85	0.781	2695.513	30026.15	2409.744	0.662	21054.68	1320.26	ADCP
DATA_20070916120850_000r.000	35000.73	83.503	2667.974	29850.54	2399.138	-0.428	20598.41	1303.49	ADCP
DATA_20070916122254_000r.000	-111.329	-27.559	-12.638	-59.553	-10.313	-1.266	1480.28	158.15	ADCP
DATA_20070916132500_000r.000	232.292	6.144	29.427	168.128	23.151	5.442	1313.05	132.72	ADCP
DATA_20070916140409_000r.000	60.192	6.709	7.526	41.231	0.677	4.05	106.11	20.19	ADCP
DATA_20070916140653_000r.000	30451.09	203.036	1912.225	25842.38	2490.207	3.241	20520.55	1025.72	ADCP
DATA_20070916142730_000r.000	10531.83	48.423	1219.677	8334.421	919.952	9.359	7969.04	679.56	ADCP
Average	21502.28	38.347	1668.321	18270.39	1523.525	1.705	13389.27	853.47	
Std. Dev.	16534.52	65.677	1243.363	14152.7	1142.675	4.231	9416.52	554.93	
Std./| Avg.|	0.77	1.71	0.75	0.77	0.75	2.48	0.7	0.65	

File Name(PYAY)	Total Q [m^3/s]	Left Q [m^3/s]	Top Q [m^3/s]	Meas. Q [m^3/s]	Bottom Q [m^3/s]	Right Q [m^3/s]	Total Area [m^2]	Width [m]	Depth Ref.
DATA_002r.000	38650.18	43.702	2405.27	33353.19	2841.7	6.322	19924.1	1270.7	ADCP
DATA_003r.000	38531.44	45.97	2280.878	33694.18	2506.654	3.756	20632.36	1246.32	ADCP
DATA_004r.000	37723.03	2.029	2199.601	33006.35	2502.581	12.467	21325.48	1287.67	ADCP
DATA_005r.000	37265.89	47.517	2378.076	32336.09	2498.991	5.211	20050.2	1321.81	ADCP
DATA_20070811154358_000r.000	37693.09	51.262	2235.891	31940.01	3443.792	22.128	21218.64	1022.18	ADCP
DATA_20070811160200_000r.000	34069.09	85.919	2085.693	29465.86	2429.354	2.256	26023.91	1089.47	ADCP
DATA_20070811162020_000r.000	36705.05	26.727	2145.185	30708.2	3788.07	36.868	21781.35	1016.79	ADCP
Average	37233.97	43.304	2247.228	32071.98	2858.735	12.716	21565.15	1179.28	
Std. Dev.	1551.146	25.439	117	1521.238	543.267	12.642	2080.18	131.69	
Std./| Avg.|	0.04	0.59	0.05	0.05	0.19	0.99	0.1	0.11	

File Name	Total Q [m^3/s]	Left Q [m^3/s]	Top Q [m^3/s]	Meas. Q [m^3/s]	Bottom Q [m^3/s]	Right Q [m^3/s]	Total Area [m^2]	Width [m]	Depth Ref.
DATA_20070916103742_000r.000	34388.84	19.738	2732.993	29369.27	2273.094	-6.255	20062.69	1283.82	ADCP
DATA_20070916111322_000r.000	34594.13	0.841	2677.421	29536.53	2377.165	2.172	20786.01	1316.59	ADCP
DATA_20070916113050_000r.000	34742.21	41.854	2753.089	29594.75	2352.436	0.075	20001.83	1294.17	ADCP
DATA_20070916115051_000r.000	35132.85	0.781	2695.513	30026.15	2409.744	0.662	21054.68	1320.26	ADCP
DATA_20070916120850_000r.000	35000.73	83.503	2667.974	29850.54	2399.138	-0.428	20598.41	1303.49	ADCP
DATA_20070916122254_000r.000	-111.329	-27.559	-12.638	-59.553	-10.313	-1.266	1480.28	158.15	ADCP
DATA_20070916132500_000r.000	232.292	6.144	29.427	168.128	23.151	5.442	1313.05	132.72	ADCP
DATA_20070916140409_000r.000	60.192	6.709	7.526	41.231	0.677	4.05	106.11	20.19	ADCP
DATA_20070916140653_000r.000	30451.09	203.036	1912.225	25842.38	2490.207	3.241	20520.55	1025.72	ADCP
DATA_20070916142730_000r.000	10531.83	48.423	1219.677	8334.421	919.952	9.359	7969.04	679.56	ADCP
Average	21502.28	38.347	1668.321	18270.39	1523.525	1.705	13389.27	853.47	
Std. Dev.	16534.52	65.677	1243.363	14152.7	1142.675	4.231	9416.52	554.93	
Std./| Avg.|	0.77	1.71	0.75	0.77	0.75	2.48	0.7	0.65	

File Name(SEIKTHA)	Total Q [m³/s]	Left Q [m³/s]	Top Q [m³/s]	Meas. Q [m³/s]	Bottom Q [m³/s]	Right Q [m³/s]	Total Area [m²]	Width [m]	Depth Ref.
DATA_20110402173629_000r.000	4764.752	28.275	655.742	3662.733	413.293	4.709	7567.99	974.18	ADCP
DATA_20110402175319_000r.000	4726.95	124.244	492.274	3743.692	363.053	3.688	7044.02	729.73	ADCP
DATA_20110402180824_000r.000	4950.899	54.076	669.63	3787.181	435.9	4.112	7462.96	936.69	ADCP
DATA_20110402182429_000r.000	4768.922	38.595	497.24	3843.051	384.064	5.971	7417.15	739.86	ADCP
Average	4802.881	61.298	578.721	3759.164	399.077	4.62	7373.03	845.12	
Std. Dev.	100.469	43.283	97.141	76.071	32.048	0.993	228.25	128.37	
Std./| Avg.|	0.02	0.71	0.17	0.02	0.08	0.21	0.03	0.15	

File Name(SEIKTHA)	Total Q [m³/s]	Left Q [m³/s]	Top Q [m³/s]	Meas. Q [m³/s]	Bottom Q [m³/s]	Right Q [m³/s]	Total Area [m²]	Width [m]	Depth Ref.
DATA_20110403080632_000r.000	3817.067	62.818	369.625	3103.729	277.575	3.321	6479.65	550.93	ADCP
DATA_20110403081836_000r.000	4698.838	27.383	616.664	3648.58	399.995	6.216	7501.69	966.12	ADCP
DATA_20110403082824_000r.000	4567.509	4.216	542.117	3641.075	376.198	3.902	7186.56	736.9	ADCP
DATA_20110403083805_000r.000	4999.91	10.108	845.637	3658.066	481.272	4.828	7276.47	954.6	ADCP
Average	4520.831	26.131	593.511	3512.862	383.76	4.567	7111.09	802.14	
Std. Dev.	502.88	26.359	197.374	272.844	83.874	1.263	441.34	197.91	
Std./| Avg.|	0.11	1.01	0.33	0.08	0.22	0.28	0.06	0.25	

File Name(PYAY)	Total Q [m^3/s]	Left Q [m^3/s]	Top Q [m^3/s]	Meas. Q [m^3/s]	Bottom Q [m^3/s]	Right Q [m^3/s]	Total Area [m^2]	Width [m]	Depth Ref.
DATA_20110403165020_000r.000	4647.047	4.551	488.698	3747.212	379.1	27.487	8630.9	947.11	ADCP
DATA_20110403165912_000r.000	4568.423	11.502	477.984	3699.443	372.891	6.603	8496.87	915.13	ADCP
DATA_20110403170821_000r.000	4664.954	13.226	486.958	3762.909	387.341	14.521	8653.22	918.2	ADCP
DATA_20110403171542_000r.000	4669.526	10.686	492.954	3771.523	389.412	4.952	8556.7	914.21	ADCP
Average	4637.488	9.991	486.648	3745.272	382.186	13.39	8584.42	923.66	
Std. Dev.	47.054	3.778	6.301	32.168	7.631	10.284	71.48	15.72	
Std./| Avg.|	0.01	0.38	0.01	0.01	0.02	0.77	0.01	0.02	

File Name(PYAY)	Total Q [m^3/s]	Left Q [m^3/s]	Top Q [m^3/s]	Meas. Q [m^3/s]	Bottom Q [m^3/s]	Right Q [m^3/s]	Total Area [m^2]	Width [m]	Depth Ref.
DATA_20110404081444_000r.000	4725.41	-1.462	471.571	3753.94	471.363	29.997	8920.71	936.07	ADCP
DATA_20110404082446_000r.000	4598.773	11.818	481.477	3705.154	388.923	11.402	8531.65	905.14	ADCP
DATA_20110404083428_000r.000	4443.517	11.379	454.262	3579.644	364.92	33.314	8490.16	895.93	ADCP
DATA_20110404084257_000r.000	4538.932	7.2	476.389	3678.762	371.644	4.937	8448.58	914.69	ADCP
Average	4576.658	7.234	470.925	3679.375	399.213	19.913	8597.77	912.96	
Std. Dev.	117.991	6.159	11.822	73.42	49.152	13.88	217.95	17.2	
Std./| Avg.|	0.03	0.85	0.03	0.02	0.12	0.7	0.03	0.02	

File Name(PYAY)	Total Q [m³/s]	Left Q [m³/s]	Top Q [m³/s]	Meas. Q [m³/s]	Bottom Q [m³/s]	Right Q [m³/s]	Total Area [m²]	Width [m]	Depth Ref.
DATA_20110405053448_000r.000	26.84	-0.336	1.74	17.264	2.576	5.596	1082.48	93.91	ADCP
DATA_20110405054908_000r.000	4309.948	25.914	46.058	4074.765	220.599	-57.387	13147.24	887.61	ADCP
DATA_20110405055551_000r.000	4498.719	16.571	114.949	4169.723	263.084	-65.608	13454.83	708.97	ADCP
DATA_20110405060229_000r.000	4092.661	23.814	100.191	3789.367	257.732	-78.444	12082.01	795.85	ADCP
DATA_20110405060800_000r.000	4024.352	13.108	109.489	3698.448	248.242	-44.934	13665.02	680.49	ADCP
Average	3390.504	15.814	74.485	3149.913	198.447	-48.155	10686.32	633.36	
Std. Dev.	1889.613	10.425	49.049	1762.005	110.712	32.43	5403.13	312.25	
Std./| Avg.|	0.56	0.66	0.66	0.56	0.56	0.67	0.51	0.49	

File Name(PYAY)	Total Q [m³/s]	Left Q [m³/s]	Top Q [m³/s]	Meas. Q [m³/s]	Bottom Q [m³/s]	Right Q [m³/s]	Total Area [m²]	Width [m]	Depth Ref.
DATA_20110405074453_000r.000	4499.917	25.649	661.407	3257.203	544.025	11.634	9049.09	1062.1	ADCP
DATA_20110405075212_000r.000	4404.23	27.04	607.875	3242.892	525.08	1.344	8361.29	877.8	ADCP
DATA_20110405075958_000r.000	4328.886	20.216	603.392	3161.162	529.889	14.227	8826.43	976.2	ADCP
DATA_20110405080830_000r.000	4398.784	31.477	605.08	3233.134	527.788	1.304	8416.85	890.99	ADCP
DATA_20110405090709_000r.000	3970.217	19.977	106.072	3672.339	226.693	-54.865	13457.93	777.67	ADCP
DATA_20110405091349_000r.000	4049.48	12.906	174.493	3648.439	255.645	-42.002	13979.11	665.39	ADCP
DATA_20110405092016_000r.000	3757.983	13.943	165.106	3394.826	240.519	-56.411	13291.25	806.14	ADCP
DATA_20110405092708_000r.000	3915.35	3.839	178.698	3529.88	240.739	-37.806	13805.59	669.12	ADCP
Average	4165.606	19.381	387.765	3392.484	386.297	-20.322	11148.44	840.67	
Std. Dev.	275.21	8.931	249.334	200.818	155.728	30.292	2673.34	139.69	
Std./| Avg.|	0.07	0.46	0.64	0.06	0.4	1.49	0.24	0.17	

File Name(PYAY)	Total Q [m^3/s]	Left Q [m^3/s]	Top Q [m^3/s]	Meas. Q [m^3/s]	Bottom Q [m^3/s]	Right Q [m^3/s]	Total Area [m^2]	Width [m]	Depth Ref.
DATA_20110405143826_000r.000	4372.289	25.581	598.443	3211.796	532.547	3.921	8688.97	923.45	ADCP
DATA_20110405144842_000r.000	4339.733	22.489	594.255	3190.34	516.709	15.941	8825.55	966.87	ADCP
DATA_20110405145637_000r.000	4336.639	27.463	597.353	3182.988	519.61	9.225	8468.07	900	ADCP
DATA_20110405150513_000r.000	4395.313	27.407	624.991	3186.272	537.244	19.399	8744.72	968.79	ADCP
DATA_20110405162346_000r.000	3831.671	26.463	142.957	3469.611	227.675	-35.033	13484.68	828.06	ADCP
DATA_20110405163040_000r.000	4004.366	30.948	169.896	3600.214	246.36	-43.052	14068.68	661.15	ADCP
DATA_20110405164206_000r.000	3862.136	77.837	133.453	3527.681	222.117	-98.952	12939.74	759.51	ADCP
DATA_20110405164700_000r.000	4377.194	63.706	187.371	3907.275	267.816	-48.975	13230.61	625.29	ADCP
Average	4189.918	37.737	381.09	3409.522	383.76	-22.191	11056.38	829.14	
Std. Dev.	246.316	20.867	238.777	264.572	153.362	41.511	2559.83	134.7	
Std./| Avg.|	0.06	0.55	0.63	0.08	0.4	1.87	0.23	0.16	

APPENDIX D

Pressure, Turbidity and Temperature data of Seiktha (2006 and 2007)

AQUAlogger 210TYPT Logger (Seiktha-03/12/2006)			
Time code	Pressure (bar)	Turbidity (FTU)	Temperature (°C)
3/12/2006 12:15	1.01	0.24	33.61
3/12/2006 12:15	1.01	0.24	33.68
3/12/2006 12:15	1.01	0.25	33.72
3/12/2006 12:15	1.01	0.24	33.81
3/12/2006 12:16	1.01	0.23	33.84
3/12/2006 12:16	1.24	147.74	25.45
3/12/2006 12:16	1.67	163.84	25.27
3/12/2006 12:16	2.18	149.71	25.17
3/12/2006 12:17	2.61	155.55	25.12
3/12/2006 12:17	2.53	149.85	25.11
3/12/2006 12:17	2.49	158.15	25.07
3/12/2006 12:17	2.42	144.26	25.04
3/12/2006 12:18	2.33	155.22	25.02
3/12/2006 12:18	2.31	167.60	25.01
3/12/2006 12:18	2.34	146.32	25.01
3/12/2006 12:18	2.31	140.17	24.99
3/12/2006 12:19	2.35	136.95	24.99
3/12/2006 12:19	2.57	140.95	24.98
3/12/2006 12:19	2.61	147.22	25.03
3/12/2006 12:19	2.61	148.38	25.01
3/12/2006 12:20	2.62	148.39	24.97
3/12/2006 12:20	2.57	159.73	24.94
3/12/2006 12:20	1.80	139.18	24.92
3/12/2006 12:20	1.02	144.26	25.02
3/12/2006 12:21	1.01	0.24	24.96
3/12/2006 12:21	1.01	0.24	25.10
3/12/2006 12:21	1.01	0.23	25.17
3/12/2006 12:21	1.01	0.24	25.25
3/12/2006 12:22	1.01	0.24	25.15
3/12/2006 12:22	1.01	0.24	25.18
3/12/2006 12:22	1.01	0.25	25.18
3/12/2006 12:22	1.01	0.24	25.18
3/12/2006 12:23	1.01	0.25	25.14
3/12/2006 12:23	1.01	0.24	25.19
3/12/2006 12:23	1.01	0.24	25.10
3/12/2006 12:23	1.01	0.24	25.12
3/12/2006 12:24	1.12	146.84	25.00
3/12/2006 12:24	1.84	130.78	24.93
3/12/2006 12:24	1.95	141.13	24.92
3/12/2006 12:24	1.77	141.46	24.92
3/12/2006 12:25	1.27	143.30	24.96
3/12/2006 12:25	1.01	0.25	24.93
3/12/2006 12:25	1.01	0.24	24.94
3/12/2006 12:25	1.01	0.23	25.03
3/12/2006 12:26	1.01	0.24	25.08
3/12/2006 12:26	1.01	0.25	24.95
3/12/2006 12:26	1.07	140.17	24.96
3/12/2006 12:26	1.13	125.43	24.94
3/12/2006 12:27	1.01	0.24	24.82
3/12/2006 12:27	1.01	0.24	25.02
3/12/2006 12:27	1.01	0.23	25.19
3/12/2006 12:27	1.01	0.25	25.10
3/12/2006 12:28	1.01	0.25	25.02
3/12/2006 12:28	1.01	0.24	24.97

AQUAlogger 210TYPT Logger (Seiktha-15/07/2007)			
Time code	Pressure (bar)	Turbidity (FTU)	Temperature (°C)
10:50:04 15/07/2007	1.00	0.24	28.04
10:50:05 15/07/2007	1.00	0.24	28.03
10:50:06 15/07/2007	1.00	0.25	28.02
10:50:14 15/07/2007	1.00	0.23	28.01
10:50:15 15/07/2007	1.00	0.24	28.00
10:50:16 15/07/2007	1.00	0.24	28.00
10:50:24 15/07/2007	1.00	0.24	28.02
10:50:25 15/07/2007	1.00	0.24	28.01
10:50:26 15/07/2007	1.00	0.24	28.00
10:50:34 15/07/2007	1.00	0.24	28.02
10:50:35 15/07/2007	1.00	0.25	28.02
10:50:36 15/07/2007	1.00	0.24	28.02
10:50:44 15/07/2007	1.00	0.24	28.05
10:50:45 15/07/2007	1.00	0.24	28.04
10:50:46 15/07/2007	1.00	0.25	28.04
10:50:54 15/07/2007	1.00	0.24	28.08
10:50:55 15/07/2007	1.00	0.24	28.07
10:50:56 15/07/2007	1.00	0.24	28.07
10:51:04 15/07/2007	1.00	0.24	28.04
10:51:05 15/07/2007	1.00	0.24	27.97
10:51:06 15/07/2007	1.00	0.24	27.90
10:51:14 15/07/2007	1.50	392.72	28.36
10:51:15 15/07/2007	1.57	476.62	28.36
10:51:16 15/07/2007	1.54	437.47	28.37
10:51:24 15/07/2007	1.39	508.65	28.38
10:51:25 15/07/2007	1.39	534.90	28.38
10:51:26 15/07/2007	1.36	464.90	28.38
10:51:34 15/07/2007	1.39	445.47	28.37
10:51:35 15/07/2007	1.41	469.31	28.38
10:51:36 15/07/2007	1.41	413.83	28.38
10:51:44 15/07/2007	1.36	425.80	28.39
10:51:45 15/07/2007	1.38	496.67	28.38
10:51:46 15/07/2007	1.36	467.72	28.38
10:51:54 15/07/2007	1.33	477.07	28.38
10:51:55 15/07/2007	1.30	445.41	28.38
10:51:56 15/07/2007	1.29	464.18	28.38
10:52:04 15/07/2007	1.32	472.36	28.38
10:52:05 15/07/2007	1.34	413.12	28.38
10:52:06 15/07/2007	1.34	468.99	28.38
10:52:14 15/07/2007	1.34	433.58	28.39
10:52:15 15/07/2007	1.35	497.21	28.38
10:52:16 15/07/2007	1.35	428.39	28.38
10:52:24 15/07/2007	1.31	490.72	28.38
10:52:25 15/07/2007	1.30	447.05	28.38
10:52:26 15/07/2007	1.32	492.64	28.38
10:52:34 15/07/2007	1.32	477.60	28.39
10:52:35 15/07/2007	1.26	434.99	28.38
10:52:36 15/07/2007	1.24	511.17	28.38
10:52:44 15/07/2007	1.25	507.24	28.38
10:52:45 15/07/2007	1.26	440.44	28.38
10:52:46 15/07/2007	1.27	493.28	28.38
10:52:54 15/07/2007	1.20	496.86	28.38
10:52:55 15/07/2007	1.19	430.95	28.38
10:52:56 15/07/2007	1.19	498.66	28.38

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3/12/2006 12:28	1.06	140.50	24.90
3/12/2006 12:29	1.09	128.66	24.90
3/12/2006 12:29	1.15	136.72	24.90
3/12/2006 12:29	1.17	141.30	24.91
3/12/2006 12:29	1.29	140.33	24.90
3/12/2006 12:30	1.33	144.66	24.89
3/12/2006 12:30	1.34	132.71	24.89
3/12/2006 12:30	1.30	141.17	24.90
3/12/2006 12:30	1.36	149.73	24.90
3/12/2006 12:31	1.44	133.55	24.90
3/12/2006 12:31	1.52	135.64	24.88
3/12/2006 12:31	1.68	136.09	24.88
3/12/2006 12:31	1.68	140.74	24.88
3/12/2006 12:32	1.73	143.78	24.88
3/12/2006 12:32	1.91	143.59	24.88
3/12/2006 12:32	1.95	132.31	24.88
3/12/2006 12:32	1.93	134.69	24.88
3/12/2006 12:33	1.95	133.62	24.88
3/12/2006 12:33	2.02	132.13	24.88
3/12/2006 12:33	1.80	134.64	24.88
3/12/2006 12:33	1.59	141.14	24.88
3/12/2006 12:34	1.31	141.43	24.90
3/12/2006 12:34	1.27	131.16	24.88
3/12/2006 12:34	1.15	126.60	24.90
3/12/2006 12:34	1.01	0.24	24.91
3/12/2006 12:35	1.01	0.24	24.54
3/12/2006 12:35	1.01	0.24	24.66
3/12/2006 12:35	1.01	0.24	24.67
3/12/2006 12:35	1.01	0.24	24.71
3/12/2006 12:36	1.01	0.24	24.70
3/12/2006 12:36	1.01	0.24	24.68
3/12/2006 12:36	1.01	0.24	24.77
3/12/2006 12:36	1.01	0.24	24.80
3/12/2006 12:37	1.01	0.25	24.87
3/12/2006 12:37	1.01	0.24	24.97
3/12/2006 12:37	1.01	0.24	25.05
3/12/2006 12:37	1.01	0.24	25.14
3/12/2006 12:38	1.01	192.16	25.23
3/12/2006 12:38	1.01	190.61	25.26
3/12/2006 12:38	1.01	189.51	25.26
3/12/2006 12:38	1.01	0.25	25.21
3/12/2006 12:39	1.01	0.24	25.13
3/12/2006 12:39	1.01	0.24	25.21
3/12/2006 12:39	1.01	0.24	25.25
3/12/2006 12:39	1.01	0.24	25.22
3/12/2006 12:40	1.01	0.24	25.25
3/12/2006 12:40	1.01	0.24	25.25
3/12/2006 12:40	1.01	0.24	25.21
3/12/2006 12:40	1.01	0.24	25.27
3/12/2006 12:41	1.01	0.24	25.15
3/12/2006 12:41	1.10	134.54	24.91
3/12/2006 12:41	1.26	132.77	24.90
3/12/2006 12:41	1.43	136.44	24.89
3/12/2006 12:42	1.64	137.05	24.88
3/12/2006 12:42	1.85	140.50	24.88
3/12/2006 12:42	2.04	135.02	24.88
3/12/2006 12:42	2.38	163.30	24.88
3/12/2006 12:43	2.41	477.70	24.88
3/12/2006 12:43	2.41	163.75	24.88
3/12/2006 12:43	2.43	588.26	24.88
3/12/2006 12:43	2.44	516.51	24.88
3/12/2006 12:44	2.43	169.17	24.88
3/12/2006 12:44	2.43	186.82	24.88
3/12/2006 12:44	2.32	151.63	24.88

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10:53:05 15/07/2007	1.11	518.19	28.38
10:53:06 15/07/2007	1.11	434.23	28.38
10:53:14 15/07/2007	1.03	447.30	28.38
10:53:15 15/07/2007	1.02	492.61	28.38
10:53:16 15/07/2007	1.01	484.49	28.38
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10:53:34 15/07/2007	1.00	0.26	28.13
10:53:35 15/07/2007	1.00	0.24	28.12
10:53:36 15/07/2007	1.00	0.24	28.13
10:53:44 15/07/2007	1.00	0.24	28.17
10:53:45 15/07/2007	1.00	0.25	28.16
10:53:46 15/07/2007	1.00	0.24	28.16
10:53:54 15/07/2007	1.00	0.24	28.15
10:53:55 15/07/2007	1.00	0.24	28.14
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10:54:04 15/07/2007	1.00	0.23	28.15
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10:54:14 15/07/2007	1.00	0.25	28.11
10:54:15 15/07/2007	1.00	0.24	28.09
10:54:16 15/07/2007	1.00	0.24	28.09
10:54:24 15/07/2007	1.00	0.24	28.09
10:54:25 15/07/2007	1.00	0.24	28.07
10:54:26 15/07/2007	1.00	0.24	28.08
10:54:34 15/07/2007	1.00	0.24	28.00
10:54:35 15/07/2007	1.00	0.24	27.97
10:54:36 15/07/2007	1.00	0.25	27.95
10:54:44 15/07/2007	1.08	388.44	28.37
10:54:45 15/07/2007	1.06	398.83	28.37
10:54:46 15/07/2007	1.05	386.90	28.37
10:54:54 15/07/2007	1.08	390.50	28.38
10:54:55 15/07/2007	1.08	385.81	28.38
10:54:56 15/07/2007	1.08	391.04	28.38
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10:55:14 15/07/2007	1.01	6.61	28.38
10:55:15 15/07/2007	1.01	4.91	28.38
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10:55:24 15/07/2007	1.01	1.82	28.39
10:55:25 15/07/2007	1.01	0.25	28.38
10:55:26 15/07/2007	1.00	0.24	28.38
10:55:34 15/07/2007	1.00	0.23	28.25
10:55:35 15/07/2007	1.00	0.25	28.18
10:55:36 15/07/2007	1.00	0.24	28.13
10:55:44 15/07/2007	1.00	0.25	28.07
10:55:45 15/07/2007	1.00	0.25	28.06
10:55:46 15/07/2007	1.00	0.24	28.07
10:55:54 15/07/2007	1.00	0.23	28.11
10:55:55 15/07/2007	1.00	0.24	28.09
10:55:56 15/07/2007	1.00	0.25	28.09
10:56:04 15/07/2007	1.00	0.25	28.05
10:56:05 15/07/2007	1.00	0.24	28.04
10:56:06 15/07/2007	1.00	0.25	28.03
10:56:14 15/07/2007	1.00	0.24	28.02
10:56:15 15/07/2007	1.00	0.24	28.02
10:56:16 15/07/2007	1.00	0.25	28.03
10:56:24 15/07/2007	1.00	0.24	28.04
10:56:25 15/07/2007	1.00	0.24	28.04
10:56:26 15/07/2007	1.00	0.24	28.05
10:56:34 15/07/2007	1.00	0.25	27.95
10:56:35 15/07/2007	1.00	0.24	27.91

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3/12/2006 12:45	2.00	151.44	24.88
3/12/2006 12:45	1.89	158.13	24.88
3/12/2006 12:45	1.72	155.94	24.88
3/12/2006 12:45	1.18	140.62	24.89
3/12/2006 12:46	1.05	143.10	24.92
3/12/2006 12:46	1.10	141.90	24.91
3/12/2006 12:46	1.02	58.29	24.90
3/12/2006 12:46	1.02	152.04	24.90
3/12/2006 12:47	1.01	0.24	24.82
3/12/2006 12:47	1.01	0.24	25.20
3/12/2006 12:47	1.01	0.23	25.56
3/12/2006 12:47	1.01	0.25	25.62
3/12/2006 12:48	1.01	0.25	25.58
3/12/2006 12:48	1.01	0.24	25.67
3/12/2006 12:48	1.12	143.14	24.91
3/12/2006 12:48	1.35	139.84	24.90
3/12/2006 12:49	1.24	145.36	24.90
3/12/2006 12:49	1.25	129.71	24.92
3/12/2006 12:49	1.16	138.44	24.91
3/12/2006 12:49	1.02	146.26	24.93
3/12/2006 12:50	1.02	148.35	24.93
3/12/2006 12:50	1.01	0.24	24.88
3/12/2006 12:50	1.01	0.25	24.96
3/12/2006 12:50	1.01	0.24	24.87
3/12/2006 12:51	1.01	0.24	24.90
3/12/2006 12:51	1.01	0.24	24.83
3/12/2006 12:51	1.01	0.24	24.93
3/12/2006 12:51	1.05	150.63	24.91
3/12/2006 12:52	1.02	152.91	24.92
3/12/2006 12:52	1.01	0.24	24.84
3/12/2006 12:52	1.01	0.24	24.77
3/12/2006 12:52	1.01	0.25	24.77
3/12/2006 12:53	1.01	0.24	24.87
3/12/2006 12:53	1.01	0.24	25.44
3/12/2006 12:53	1.01	0.24	25.71
3/12/2006 12:53	1.01	0.25	26.08
3/12/2006 12:54	1.01	0.24	26.38
3/12/2006 12:54	1.01	0.24	26.60
3/12/2006 12:54	1.01	0.25	26.77
3/12/2006 12:54	1.01	0.24	26.97
3/12/2006 12:55	1.01	0.24	27.08
3/12/2006 12:55	1.01	0.23	27.17
3/12/2006 12:55	1.01	0.25	27.38
3/12/2006 12:55	1.01	0.24	27.27
3/12/2006 12:56	1.01	0.24	27.09
3/12/2006 12:56	1.01	0.24	27.00
3/12/2006 12:56	1.01	0.24	26.91
3/12/2006 12:56	1.01	0.25	26.90
3/12/2006 12:57	1.01	0.25	26.87
3/12/2006 12:57	1.01	0.24	26.88
3/12/2006 12:57	1.01	0.24	26.89
3/12/2006 12:57	1.01	0.24	26.88
3/12/2006 12:58	1.01	0.24	26.86
3/12/2006 12:58	1.01	0.23	27.27
3/12/2006 12:58	1.01	0.24	27.54
3/12/2006 12:58	1.01	0.24	27.55
3/12/2006 12:59	1.01	0.24	27.20
3/12/2006 12:59	1.33	115.04	25.07
3/12/2006 12:59	1.90	121.73	25.00
3/12/2006 12:59	2.25	124.71	24.98
3/12/2006 13:00	2.47	136.79	24.99
3/12/2006 13:00	2.40	134.25	25.00
3/12/2006 13:00	2.40	132.04	25.02
3/12/2006 13:00	2.41	139.07	24.99

10:56:36 15/07/2007	1.00	0.24	27.89
10:56:44 15/07/2007	1.00	0.24	27.95
10:56:45 15/07/2007	1.00	0.25	27.96
10:56:46 15/07/2007	1.00	0.24	27.97
10:56:54 15/07/2007	1.00	0.24	28.00
10:56:55 15/07/2007	1.00	0.24	27.98
10:56:56 15/07/2007	1.00	0.24	27.98
10:57:04 15/07/2007	1.00	0.24	27.93
10:57:05 15/07/2007	1.00	0.24	27.91
10:57:06 15/07/2007	1.00	0.24	27.90
10:57:14 15/07/2007	1.00	0.25	27.86
10:57:15 15/07/2007	1.00	0.24	27.85
10:57:16 15/07/2007	1.00	0.24	27.84
10:57:24 15/07/2007	1.00	0.24	27.81
10:57:25 15/07/2007	1.00	0.24	27.80
10:57:26 15/07/2007	1.00	0.24	27.80
10:57:34 15/07/2007	1.00	0.25	27.84
10:57:35 15/07/2007	1.00	0.24	27.83
10:57:36 15/07/2007	1.00	0.24	27.82
10:57:44 15/07/2007	1.00	0.24	27.81
10:57:45 15/07/2007	1.00	0.25	27.81
10:57:46 15/07/2007	1.00	0.24	27.81
10:57:54 15/07/2007	1.00	0.24	27.80
10:57:55 15/07/2007	1.00	0.24	27.79
10:57:56 15/07/2007	1.00	0.24	27.79
10:58:04 15/07/2007	1.00	0.24	27.79
10:58:05 15/07/2007	1.00	0.24	27.78
10:58:06 15/07/2007	1.00	0.24	27.77
10:58:14 15/07/2007	1.00	0.25	27.76
10:58:15 15/07/2007	1.00	0.24	27.76
10:58:16 15/07/2007	1.00	0.24	27.75
10:58:24 15/07/2007	1.00	0.24	27.74
10:58:25 15/07/2007	1.00	0.24	27.73
10:58:26 15/07/2007	1.00	0.24	27.72
10:58:34 15/07/2007	1.00	0.24	27.72
10:58:35 15/07/2007	1.00	0.24	27.71
10:58:36 15/07/2007	1.00	0.24	27.71
10:58:44 15/07/2007	1.00	0.24	27.72
10:58:45 15/07/2007	1.00	0.25	27.72
10:58:46 15/07/2007	1.00	0.25	27.71
10:58:54 15/07/2007	1.00	0.24	27.73
10:58:55 15/07/2007	1.00	0.24	27.73
10:58:56 15/07/2007	1.00	0.24	27.73
10:59:04 15/07/2007	1.00	0.25	27.73
10:59:05 15/07/2007	1.00	0.24	27.73
10:59:06 15/07/2007	1.00	0.24	27.72
10:59:14 15/07/2007	1.00	0.24	27.69
10:59:15 15/07/2007	1.00	0.24	27.67
10:59:16 15/07/2007	1.00	0.25	27.66
10:59:24 15/07/2007	1.00	0.24	27.67
10:59:25 15/07/2007	1.00	0.24	27.66
10:59:26 15/07/2007	1.00	0.23	27.67
10:59:34 15/07/2007	1.00	0.25	27.68
10:59:35 15/07/2007	1.00	0.24	27.67
10:59:36 15/07/2007	1.00	0.24	27.67
10:59:44 15/07/2007	1.00	0.25	27.68
10:59:45 15/07/2007	1.00	0.24	27.67
10:59:46 15/07/2007	1.00	0.25	27.67
10:59:54 15/07/2007	1.00	0.24	27.69
10:59:55 15/07/2007	1.00	0.24	27.68
10:59:56 15/07/2007	1.00	0.23	27.67
11:00:04 15/07/2007	1.00	0.24	27.66
11:00:05 15/07/2007	1.00	0.25	27.63
11:00:06 15/07/2007	1.00	0.24	27.63
11:00:14 15/07/2007	1.00	0.24	27.67

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3/12/2006 13:01	2.19	136.72	24.96
3/12/2006 13:01	2.16	145.85	24.96
3/12/2006 13:01	1.95	131.32	24.95
3/12/2006 13:02	1.82	140.54	24.96
3/12/2006 13:02	1.71	131.62	24.97
3/12/2006 13:02	1.66	124.76	24.97
3/12/2006 13:02	1.53	118.95	24.98
3/12/2006 13:03	1.46	117.43	24.97
3/12/2006 13:03	1.37	118.09	24.97
3/12/2006 13:03	1.21	117.42	24.97
3/12/2006 13:03	1.17	124.76	24.96
3/12/2006 13:04	1.03	123.05	24.99
3/12/2006 13:04	1.03	80.22	25.07
3/12/2006 13:04	1.01	0.25	24.82
3/12/2006 13:04	1.01	0.25	24.72
3/12/2006 13:05	1.01	0.25	24.71
3/12/2006 13:05	1.01	0.24	24.76
3/12/2006 13:05	1.01	0.25	24.76
3/12/2006 13:05	1.01	0.23	24.68
3/12/2006 13:06	1.01	0.24	24.72
3/12/2006 13:06	1.08	24.62	25.00
3/12/2006 13:06	1.73	119.77	24.98
3/12/2006 13:06	1.70	125.51	24.96
3/12/2006 13:07	1.67	119.83	24.96
3/12/2006 13:07	1.35	120.67	24.97
3/12/2006 13:07	1.01	0.27	24.88
3/12/2006 13:07	1.01	0.24	24.82
3/12/2006 13:08	1.01	0.24	24.79
3/12/2006 13:08	1.01	0.25	24.85
3/12/2006 13:08	1.01	0.24	24.88
3/12/2006 13:08	1.02	0.24	24.94
3/12/2006 13:09	1.15	143.97	24.98
3/12/2006 13:09	1.01	0.24	24.84
3/12/2006 13:09	1.01	0.24	24.60
3/12/2006 13:09	1.01	0.24	24.49
3/12/2006 13:10	1.01	0.24	24.47
3/12/2006 13:10	1.01	0.24	24.68
3/12/2006 13:10	1.01	0.24	25.21
3/12/2006 13:10	1.01	0.24	25.50
3/12/2006 13:11	1.01	0.24	25.72
3/12/2006 13:11	1.01	0.24	26.11
3/12/2006 13:11	1.01	0.24	26.37
3/12/2006 13:11	1.01	0.24	26.59
3/12/2006 13:12	1.01	0.23	26.77
3/12/2006 13:12	1.01	0.23	26.86
3/12/2006 13:12	1.01	0.24	26.95
3/12/2006 13:12	1.01	0.24	26.89
3/12/2006 13:13	1.01	0.24	26.42
3/12/2006 13:13	1.01	0.24	26.18
3/12/2006 13:13	1.01	0.24	26.21
3/12/2006 13:13	1.01	0.24	26.23
3/12/2006 13:14	1.01	0.24	26.18
3/12/2006 13:14	1.01	0.25	26.16
3/12/2006 13:14	1.01	0.24	26.15
3/12/2006 13:14	1.01	0.24	26.13
3/12/2006 13:15	1.01	0.24	26.15
3/12/2006 13:15	1.01	0.24	26.13
3/12/2006 13:15	1.01	0.24	26.15
3/12/2006 13:15	1.01	0.25	26.11
3/12/2006 13:16	1.01	0.23	26.04
3/12/2006 13:16	1.01	0.24	26.13
3/12/2006 13:16	1.01	0.24	26.32
3/12/2006 13:16	1.01	0.24	26.66
3/12/2006 13:17	1.01	0.24	26.48

11:00:15 15/07/2007	1.00	0.24	27.65
11:00:16 15/07/2007	1.00	0.24	27.64
11:00:24 15/07/2007	1.00	0.25	27.57
11:00:25 15/07/2007	1.00	0.24	27.54
11:00:26 15/07/2007	1.00	0.24	27.53
11:00:34 15/07/2007	1.00	0.24	27.51
11:00:35 15/07/2007	1.00	0.24	27.48
11:00:36 15/07/2007	1.00	0.24	27.48
11:00:44 15/07/2007	1.00	0.25	27.45
11:00:45 15/07/2007	1.00	0.24	27.44
11:00:46 15/07/2007	1.00	0.25	27.45
11:00:54 15/07/2007	1.00	0.25	27.42
11:00:55 15/07/2007	1.00	0.24	27.41
11:00:56 15/07/2007	1.00	0.24	27.41
11:01:04 15/07/2007	1.00	0.24	27.44
11:01:05 15/07/2007	1.00	0.24	27.43
11:01:06 15/07/2007	1.00	0.24	27.43
11:01:14 15/07/2007	1.00	0.25	27.44
11:01:15 15/07/2007	1.00	0.25	27.43
11:01:16 15/07/2007	1.00	0.24	27.44
11:01:24 15/07/2007	1.00	0.24	27.45
11:01:25 15/07/2007	1.00	0.24	27.45
11:01:26 15/07/2007	1.00	0.24	27.46
11:01:34 15/07/2007	1.00	0.24	27.57
11:01:35 15/07/2007	1.00	0.24	27.57
11:01:36 15/07/2007	1.00	0.25	27.57
11:01:44 15/07/2007	1.00	0.24	27.62
11:01:45 15/07/2007	1.00	0.25	27.61
11:01:46 15/07/2007	1.00	0.24	27.62
11:01:54 15/07/2007	1.00	0.24	27.67
11:01:55 15/07/2007	1.00	0.25	27.66
11:01:56 15/07/2007	1.00	0.24	27.66
11:02:04 15/07/2007	1.00	0.24	27.68
11:02:05 15/07/2007	1.00	0.24	27.67
11:02:06 15/07/2007	1.00	0.23	27.67
11:02:14 15/07/2007	1.00	0.24	27.71
11:02:15 15/07/2007	1.00	0.24	27.71
11:02:16 15/07/2007	1.00	0.24	27.71
11:02:24 15/07/2007	1.00	0.24	27.72
11:02:25 15/07/2007	1.00	0.24	27.72
11:02:26 15/07/2007	1.00	0.24	27.73
11:02:34 15/07/2007	1.00	0.24	27.75
11:02:35 15/07/2007	1.00	0.25	27.75
11:02:36 15/07/2007	1.00	0.46	27.74
11:02:44 15/07/2007	1.00	7.43	27.81
11:02:45 15/07/2007	1.00	6.39	27.81
11:02:46 15/07/2007	1.00	5.79	27.82
11:02:54 15/07/2007	1.00	4.35	27.87
11:02:55 15/07/2007	1.00	5.15	27.86
11:02:56 15/07/2007	1.00	5.80	27.86
11:03:04 15/07/2007	1.00	14.76	27.86
11:03:05 15/07/2007	1.00	17.58	27.85
11:03:06 15/07/2007	1.00	18.62	27.86
11:03:14 15/07/2007	1.00	26.82	27.87
11:03:15 15/07/2007	1.00	27.42	27.86
11:03:16 15/07/2007	1.00	28.17	27.86
11:03:24 15/07/2007	1.00	31.56	27.84
11:03:25 15/07/2007	1.00	32.15	27.84
11:03:26 15/07/2007	1.00	32.64	27.84
11:03:34 15/07/2007	1.00	35.34	27.86
11:03:35 15/07/2007	1.00	35.65	27.86
11:03:36 15/07/2007	1.00	36.17	27.86
11:03:44 15/07/2007	1.00	37.20	27.88
11:03:45 15/07/2007	1.00	37.41	27.87
11:03:46 15/07/2007	1.00	37.70	27.87

3/12/2006 13:17	1.01	0.24	26.28
3/12/2006 13:17	1.01	0.24	26.24
3/12/2006 13:17	1.01	0.24	26.14
3/12/2006 13:18	1.01	0.22	26.09
3/12/2006 13:18	1.01	0.23	26.04
3/12/2006 13:18	1.01	0.23	26.11
3/12/2006 13:18	1.01	0.25	26.09
3/12/2006 13:19	1.01	0.23	26.05
3/12/2006 13:19	1.01	0.24	26.05
3/12/2006 13:19	1.01	0.24	25.99
3/12/2006 13:19	1.01	0.24	25.95
3/12/2006 13:20	1.01	0.24	25.93
3/12/2006 13:20	1.01	0.25	25.88
3/12/2006 13:20	1.01	0.24	25.88

11:03:54 15/07/2007	1.00	39.06	27.89
11:03:55 15/07/2007	1.00	39.07	27.88
11:03:56 15/07/2007	1.00	39.16	27.88
11:04:04 15/07/2007	1.00	40.09	27.90
11:04:05 15/07/2007	1.00	40.32	27.89
11:04:06 15/07/2007	1.00	40.54	27.90
11:04:14 15/07/2007	1.00	41.78	27.90
11:04:15 15/07/2007	1.00	41.91	27.90
11:04:16 15/07/2007	1.00	42.05	27.90
11:04:24 15/07/2007	1.00	42.93	27.91
11:04:25 15/07/2007	1.00	43.07	27.91
11:04:26 15/07/2007	1.00	43.19	27.91
11:04:34 15/07/2007	1.00	43.91	27.92
11:04:35 15/07/2007	1.00	43.81	27.91
11:04:36 15/07/2007	1.00	43.87	27.92
11:04:44 15/07/2007	1.00	46.72	27.92
11:04:45 15/07/2007	1.00	46.79	27.92
11:04:46 15/07/2007	1.00	46.82	27.92
11:04:54 15/07/2007	1.00	36.40	27.93
11:04:55 15/07/2007	1.00	36.36	27.92
11:04:56 15/07/2007	1.00	36.30	27.92
11:05:04 15/07/2007	1.00	36.92	27.93
11:05:05 15/07/2007	1.00	36.98	27.92
11:05:06 15/07/2007	1.00	37.05	27.91
11:05:14 15/07/2007	1.00	37.41	27.93
11:05:15 15/07/2007	1.00	37.50	27.92
11:05:16 15/07/2007	1.00	37.47	27.92
11:05:24 15/07/2007	1.00	38.15	27.93
11:05:25 15/07/2007	1.00	38.20	27.93
11:05:26 15/07/2007	1.00	38.27	27.93
11:05:34 15/07/2007	1.00	38.80	27.94
11:05:35 15/07/2007	1.00	38.86	27.93
11:05:36 15/07/2007	1.00	38.91	27.93
11:05:44 15/07/2007	1.00	39.13	27.94
11:05:45 15/07/2007	1.00	39.19	27.93
11:05:46 15/07/2007	1.00	39.19	27.94
11:05:54 15/07/2007	1.00	39.50	27.94
11:05:55 15/07/2007	1.00	39.57	27.94
11:05:56 15/07/2007	1.00	39.61	27.94
11:06:04 15/07/2007	1.00	40.15	27.95
11:06:05 15/07/2007	1.00	40.18	27.94
11:06:06 15/07/2007	1.00	40.20	27.94
11:06:14 15/07/2007	1.00	40.44	27.95
11:06:15 15/07/2007	1.00	40.45	27.94
11:06:16 15/07/2007	1.00	40.45	27.94
11:06:24 15/07/2007	1.00	40.61	27.94
11:06:25 15/07/2007	1.00	40.65	27.94
11:06:26 15/07/2007	1.00	40.66	27.93
11:06:34 15/07/2007	1.00	40.75	27.91
11:06:35 15/07/2007	1.00	40.76	27.91
11:06:36 15/07/2007	1.00	40.78	27.91
11:06:44 15/07/2007	1.00	40.90	27.90
11:06:45 15/07/2007	1.00	40.90	27.90
11:06:46 15/07/2007	1.00	40.93	27.90
11:06:54 15/07/2007	1.00	41.00	27.91
11:06:55 15/07/2007	1.00	41.02	27.91
11:06:56 15/07/2007	1.00	41.00	27.91
11:07:04 15/07/2007	1.00	41.10	27.91
11:07:05 15/07/2007	1.00	41.15	27.90
11:07:06 15/07/2007	1.00	41.19	27.89
11:07:14 15/07/2007	1.00	41.33	27.90
11:07:15 15/07/2007	1.00	41.36	27.90
11:07:16 15/07/2007	1.00	41.38	27.91
11:07:24 15/07/2007	1.00	41.69	27.92
11:07:25 15/07/2007	1.00	41.69	27.92

11:07:26 15/07/2007	1.00	41.68	27.92
11:07:34 15/07/2007	1.00	41.64	27.93
11:07:35 15/07/2007	1.00	41.63	27.93
11:07:36 15/07/2007	1.00	41.65	27.93
11:07:44 15/07/2007	1.00	41.75	27.93
11:07:45 15/07/2007	1.00	41.75	27.92
11:07:46 15/07/2007	1.00	41.78	27.92
11:07:54 15/07/2007	1.00	41.76	27.92

Pressure, Turbidity and Temperature data of Pyay (2006 and 2007)

AQUAlogger 210TYPT Logger (Pyay-04/12/2006)			
Time code	Pressure (bar)	Turbidity (FTU)	Temperature (°C)
4/12/2006 15:40	1.01	0.25	32.84
4/12/2006 15:40	1.01	0.24	32.81
4/12/2006 15:40	1.01	0.24	32.81
4/12/2006 15:40	1.01	0.24	32.89
4/12/2006 15:40	1.01	0.24	32.86
4/12/2006 15:40	1.01	0.24	32.85
4/12/2006 15:40	1.01	0.24	32.73
4/12/2006 15:40	1.01	0.24	32.72
4/12/2006 15:40	1.01	0.24	32.70
4/12/2006 15:40	1.01	0.25	32.82
4/12/2006 15:40	1.01	0.24	32.83
4/12/2006 15:40	1.01	0.24	32.85
4/12/2006 15:40	1.01	0.25	32.96
4/12/2006 15:40	1.01	0.24	32.97
4/12/2006 15:40	1.01	0.24	32.97
4/12/2006 15:40	1.01	0.23	33.02
4/12/2006 15:40	1.01	0.24	33.03
4/12/2006 15:40	1.01	0.24	33.02
4/12/2006 15:41	1.01	0.24	33.09
4/12/2006 15:41	1.01	0.24	33.11
4/12/2006 15:41	1.01	0.24	33.13
4/12/2006 15:41	1.01	0.24	33.17
4/12/2006 15:41	1.01	0.24	33.16
4/12/2006 15:41	1.01	0.24	33.14
4/12/2006 15:41	1.01	0.24	33.15
4/12/2006 15:41	1.01	0.25	33.15
4/12/2006 15:41	1.01	0.24	33.16
4/12/2006 15:41	1.01	0.23	33.18
4/12/2006 15:41	1.01	0.24	33.18
4/12/2006 15:41	1.01	0.24	33.17
4/12/2006 15:41	1.01	0.25	33.19
4/12/2006 15:41	1.01	0.24	33.19
4/12/2006 15:41	1.01	0.24	33.21
4/12/2006 15:41	1.01	0.24	33.25
4/12/2006 15:41	1.01	0.24	33.27
4/12/2006 15:41	1.01	0.25	33.28
4/12/2006 15:42	1.01	0.24	33.41
4/12/2006 15:42	1.01	0.25	33.41
4/12/2006 15:42	1.01	0.24	33.44
4/12/2006 15:42	1.01	0.24	33.21
4/12/2006 15:42	1.01	0.25	31.08
4/12/2006 15:42	1.04	0.55	27.10
4/12/2006 15:42	1.44	126.35	25.45
4/12/2006 15:42	1.48	133.61	25.41
4/12/2006 15:42	1.51	128.36	25.39
4/12/2006 15:42	1.66	136.87	25.16
4/12/2006 15:42	1.68	125.61	25.16
4/12/2006 15:42	1.70	126.50	25.16
4/12/2006 15:42	1.86	125.64	25.10
4/12/2006 15:42	1.90	128.46	25.09
4/12/2006 15:42	1.92	126.17	25.06
4/12/2006 15:42	2.03	131.29	24.99
4/12/2006 15:42	2.04	130.50	24.99
4/12/2006 15:42	2.04	124.96	25.00
4/12/2006 15:43	2.11	131.69	24.95
4/12/2006 15:43	2.11	131.98	24.96
4/12/2006 15:43	2.12	125.43	24.96
4/12/2006 15:43	2.29	126.55	24.94
4/12/2006 15:43	2.31	131.23	24.93

AQUAlogger 210TYPT Logger (Pyay-07/07/2007)			
Time code	Pressure (bar)	Turbidity (FTU)	Temperature (°C)
7/7/2007 13:50	1.00	0.24	31.24
7/7/2007 13:50	1.00	0.23	31.22
7/7/2007 13:50	1.00	0.24	31.21
7/7/2007 13:50	1.00	0.25	31.25
7/7/2007 13:50	1.00	0.24	31.24
7/7/2007 13:50	1.00	0.24	31.24
7/7/2007 13:50	1.00	0.24	31.28
7/7/2007 13:50	1.00	0.24	31.28
7/7/2007 13:50	1.00	0.24	31.28
7/7/2007 13:50	1.00	0.23	31.36
7/7/2007 13:50	1.00	0.23	31.37
7/7/2007 13:50	1.00	0.24	31.39
7/7/2007 13:50	1.00	0.24	31.45
7/7/2007 13:50	1.00	0.25	31.46
7/7/2007 13:50	1.00	0.25	31.47
7/7/2007 13:50	1.00	0.24	31.59
7/7/2007 13:50	1.00	0.24	31.60
7/7/2007 13:50	1.00	0.24	31.61
7/7/2007 13:51	1.00	0.24	31.71
7/7/2007 13:51	1.00	0.24	31.73
7/7/2007 13:51	1.00	0.24	31.75
7/7/2007 13:51	1.00	0.25	31.88
7/7/2007 13:51	1.00	0.23	31.89
7/7/2007 13:51	1.00	0.24	31.90
7/7/2007 13:51	1.00	0.24	31.94
7/7/2007 13:51	1.00	0.24	31.93
7/7/2007 13:51	1.00	0.24	31.93
7/7/2007 13:51	1.00	0.24	31.99
7/7/2007 13:51	1.00	0.24	31.98
7/7/2007 13:51	1.00	0.23	31.97
7/7/2007 13:51	1.00	0.24	32.00
7/7/2007 13:51	1.00	0.25	31.98
7/7/2007 13:51	1.00	0.24	31.98
7/7/2007 13:51	1.00	0.24	32.01
7/7/2007 13:51	1.00	0.24	31.98
7/7/2007 13:51	1.00	0.24	31.97
7/7/2007 13:52	1.00	0.25	32.01
7/7/2007 13:52	1.00	0.25	32.01
7/7/2007 13:52	1.00	0.24	32.02
7/7/2007 13:52	1.00	0.25	32.07
7/7/2007 13:52	1.00	0.24	32.06
7/7/2007 13:52	1.00	0.24	32.07
7/7/2007 13:52	1.00	0.24	32.12
7/7/2007 13:52	1.00	0.24	32.11
7/7/2007 13:52	1.00	0.24	32.11
7/7/2007 13:52	1.00	0.24	32.13
7/7/2007 13:52	1.00	0.25	32.08
7/7/2007 13:52	1.00	0.24	32.05
7/7/2007 13:52	1.00	0.24	31.88
7/7/2007 13:52	1.00	0.24	31.89
7/7/2007 13:52	1.00	0.25	31.89
7/7/2007 13:52	1.00	0.24	31.98
7/7/2007 13:52	1.00	0.25	31.99
7/7/2007 13:52	1.00	0.23	32.01
7/7/2007 13:53	1.00	0.25	32.15
7/7/2007 13:53	1.00	0.24	32.15
7/7/2007 13:53	1.00	0.24	32.16
7/7/2007 13:53	1.00	0.24	32.13
7/7/2007 13:53	1.00	0.24	32.12

4/12/2006 15:43	2.33	129.09	24.94	7/7/2007 13:53	1.00	0.25	32.13
4/12/2006 15:43	2.50	128.17	24.94	7/7/2007 13:53	1.00	0.24	32.15
4/12/2006 15:43	2.53	128.59	24.94	7/7/2007 13:53	1.00	0.24	32.13
4/12/2006 15:43	2.55	124.38	24.91	7/7/2007 13:53	1.00	0.24	32.13
4/12/2006 15:43	2.68	131.41	24.92	7/7/2007 13:53	1.00	0.24	32.25
4/12/2006 15:43	2.70	125.58	24.91	7/7/2007 13:53	1.00	0.25	32.26
4/12/2006 15:43	2.73	125.56	24.90	7/7/2007 13:53	1.00	0.24	32.27
4/12/2006 15:43	2.87	131.94	24.89	7/7/2007 13:53	1.00	0.24	32.38
4/12/2006 15:43	2.84	129.66	24.86	7/7/2007 13:53	1.00	0.24	32.38
4/12/2006 15:43	2.87	128.76	24.85	7/7/2007 13:53	1.00	0.24	32.39
4/12/2006 15:43	3.04	131.45	24.87	7/7/2007 13:53	1.00	0.23	32.42
4/12/2006 15:43	3.05	130.00	24.86	7/7/2007 13:53	1.00	0.25	32.41
4/12/2006 15:43	3.05	132.58	24.87	7/7/2007 13:53	1.00	0.25	32.42
4/12/2006 15:44	3.08	131.62	24.88	7/7/2007 13:54	1.00	0.24	32.50
4/12/2006 15:44	3.09	129.95	24.85	7/7/2007 13:54	1.00	0.25	32.49
4/12/2006 15:44	3.10	133.32	24.85	7/7/2007 13:54	1.00	0.25	32.50
4/12/2006 15:44	3.17	126.63	24.83	7/7/2007 13:54	1.00	0.25	32.56
4/12/2006 15:44	3.19	126.74	24.82	7/7/2007 13:54	1.00	0.24	32.56
4/12/2006 15:44	3.19	130.48	24.82	7/7/2007 13:54	1.00	0.24	32.56
4/12/2006 15:44	3.25	132.17	24.83	7/7/2007 13:54	1.00	0.25	32.62
4/12/2006 15:44	3.26	138.25	24.83	7/7/2007 13:54	1.00	0.24	32.61
4/12/2006 15:44	3.26	126.46	24.83	7/7/2007 13:54	1.00	0.24	32.62
4/12/2006 15:44	3.28	133.32	24.83	7/7/2007 13:54	1.00	0.25	32.65
4/12/2006 15:44	3.28	126.79	24.83	7/7/2007 13:54	1.00	0.24	32.64
4/12/2006 15:44	3.28	125.47	24.84	7/7/2007 13:54	1.00	0.24	32.64
4/12/2006 15:44	3.28	129.14	24.82	7/7/2007 13:54	1.00	0.23	32.64
4/12/2006 15:44	3.30	130.55	24.81	7/7/2007 13:54	1.00	0.24	32.62
4/12/2006 15:44	3.30	141.01	24.81	7/7/2007 13:54	1.00	0.24	32.61
4/12/2006 15:44	3.32	131.96	24.84	7/7/2007 13:54	1.00	0.24	32.52
4/12/2006 15:44	3.32	123.99	24.84	7/7/2007 13:54	1.00	0.24	32.50
4/12/2006 15:44	3.32	130.31	24.83	7/7/2007 13:54	1.00	0.25	32.50
4/12/2006 15:45	3.34	131.08	24.82	7/7/2007 13:55	1.00	0.24	32.46
4/12/2006 15:45	3.34	136.73	24.82	7/7/2007 13:55	1.00	0.24	32.45
4/12/2006 15:45	3.34	133.57	24.82	7/7/2007 13:55	1.00	0.24	32.44
4/12/2006 15:45	3.35	131.97	24.83	7/7/2007 13:55	1.00	0.24	32.43
4/12/2006 15:45	3.35	131.91	24.82	7/7/2007 13:55	1.00	0.24	32.42
4/12/2006 15:45	3.35	127.88	24.81	7/7/2007 13:55	1.00	0.24	32.42
4/12/2006 15:45	3.44	128.99	24.82	7/7/2007 13:55	1.00	0.24	32.45
4/12/2006 15:45	3.39	126.70	24.79	7/7/2007 13:55	1.00	0.24	32.44
4/12/2006 15:45	3.41	125.02	24.78	7/7/2007 13:55	1.00	0.24	32.44
4/12/2006 15:45	3.47	137.51	24.80	7/7/2007 13:55	1.00	0.24	32.42
4/12/2006 15:45	3.47	126.05	24.79	7/7/2007 13:55	1.00	0.24	32.40
4/12/2006 15:45	3.47	132.80	24.79	7/7/2007 13:55	1.00	0.24	32.39
4/12/2006 15:45	3.46	129.19	24.79	7/7/2007 13:55	1.00	0.24	32.48
4/12/2006 15:45	3.46	128.01	24.78	7/7/2007 13:55	1.00	0.24	32.43
4/12/2006 15:45	3.46	125.70	24.78	7/7/2007 13:55	1.00	0.25	32.43
4/12/2006 15:45	3.48	135.05	24.79	7/7/2007 13:55	1.00	0.24	28.63
4/12/2006 15:45	3.48	130.80	24.78	7/7/2007 13:55	1.00	0.24	28.25
4/12/2006 15:45	3.45	126.95	24.78	7/7/2007 13:55	1.00	0.24	27.97
4/12/2006 15:46	3.48	129.62	24.78	7/7/2007 13:56	1.04	499.31	27.68
4/12/2006 15:46	3.47	139.03	24.77	7/7/2007 13:56	1.06	493.13	27.66
4/12/2006 15:46	3.46	132.56	24.76	7/7/2007 13:56	1.08	469.82	27.66
4/12/2006 15:46	3.43	130.77	24.76	7/7/2007 13:56	1.14	483.13	27.61
4/12/2006 15:46	3.42	128.60	24.75	7/7/2007 13:56	1.15	492.71	27.60
4/12/2006 15:46	3.45	125.59	24.75	7/7/2007 13:56	1.17	483.17	27.59
4/12/2006 15:46	3.37	126.19	24.76	7/7/2007 13:56	1.19	506.06	27.58
4/12/2006 15:46	3.35	132.11	24.75	7/7/2007 13:56	1.19	502.01	27.57
4/12/2006 15:46	3.36	127.60	24.75	7/7/2007 13:56	1.20	498.28	27.57
4/12/2006 15:46	3.25	131.28	24.74	7/7/2007 13:56	1.21	487.40	27.57
4/12/2006 15:46	3.24	133.58	24.74	7/7/2007 13:56	1.22	490.72	27.56
4/12/2006 15:46	3.22	127.29	24.74	7/7/2007 13:56	1.22	522.69	27.56
4/12/2006 15:46	3.10	134.83	24.74	7/7/2007 13:56	1.22	478.67	27.56
4/12/2006 15:46	3.09	132.64	24.75	7/7/2007 13:56	1.22	511.82	27.55
4/12/2006 15:46	3.06	127.35	24.75	7/7/2007 13:56	1.23	488.13	27.55
4/12/2006 15:46	2.91	127.24	24.74	7/7/2007 13:56	1.31	492.21	27.56

4/12/2006 15:46	2.84	124.96	24.73
4/12/2006 15:46	2.79	134.55	24.73
4/12/2006 15:47	2.67	126.90	24.75
4/12/2006 15:47	2.67	127.33	24.74
4/12/2006 15:47	2.67	133.71	24.74
4/12/2006 15:47	2.63	128.01	24.75
4/12/2006 15:47	2.63	129.12	24.74
4/12/2006 15:47	2.63	128.65	24.74
4/12/2006 15:47	2.53	136.97	24.74
4/12/2006 15:47	2.52	127.53	24.74
4/12/2006 15:47	2.49	125.50	24.73
4/12/2006 15:47	2.37	126.22	24.73
4/12/2006 15:47	2.34	125.18	24.73
4/12/2006 15:47	2.30	125.72	24.73
4/12/2006 15:47	2.21	127.11	24.73
4/12/2006 15:47	2.19	125.44	24.73
4/12/2006 15:47	2.18	131.65	24.72
4/12/2006 15:47	1.92	126.34	24.74
4/12/2006 15:47	1.92	128.91	24.73
4/12/2006 15:47	1.92	137.69	24.73
4/12/2006 15:48	1.93	123.59	24.75
4/12/2006 15:48	1.92	128.87	24.74
4/12/2006 15:48	1.93	125.86	24.73
4/12/2006 15:48	1.93	132.29	24.76
4/12/2006 15:48	1.93	132.80	24.76
4/12/2006 15:48	1.92	146.74	24.75
4/12/2006 15:48	1.67	132.21	24.72
4/12/2006 15:48	1.63	145.29	24.71
4/12/2006 15:48	1.61	139.64	24.71
4/12/2006 15:48	1.22	130.91	24.71
4/12/2006 15:48	1.16	134.44	24.71
4/12/2006 15:48	1.12	150.05	24.71
4/12/2006 15:48	1.01	0.25	24.66
4/12/2006 15:48	1.01	0.24	24.66
4/12/2006 15:48	1.01	0.24	24.63
4/12/2006 15:48	1.01	0.25	24.57
4/12/2006 15:48	1.01	0.24	24.56
4/12/2006 15:48	1.01	0.24	24.54
4/12/2006 15:49	1.01	0.25	24.39
4/12/2006 15:49	1.01	0.24	24.40
4/12/2006 15:49	1.01	0.23	24.40
4/12/2006 15:49	1.01	0.24	24.48
4/12/2006 15:49	1.01	0.24	24.46
4/12/2006 15:49	1.01	0.24	24.45
4/12/2006 15:49	1.01	0.24	24.44
4/12/2006 15:49	1.01	0.24	24.47
4/12/2006 15:49	1.01	0.24	24.48
4/12/2006 15:49	1.01	0.24	24.48
4/12/2006 15:49	1.01	0.24	24.47
4/12/2006 15:49	1.01	0.24	24.47
4/12/2006 15:49	1.01	0.24	24.51
4/12/2006 15:49	1.01	0.24	24.50
4/12/2006 15:49	1.01	0.25	24.50
4/12/2006 15:49	1.01	0.24	24.52
4/12/2006 15:49	1.01	0.25	24.52
4/12/2006 15:49	1.01	0.24	24.52
4/12/2006 15:50	1.01	0.24	24.61
4/12/2006 15:50	1.01	0.23	24.61
4/12/2006 15:50	1.01	0.24	24.61
4/12/2006 15:50	1.01	0.24	24.64
4/12/2006 15:50	1.01	0.24	24.64
4/12/2006 15:50	1.01	0.24	24.64
4/12/2006 15:50	1.01	0.24	24.69
4/12/2006 15:50	1.01	0.24	24.68
4/12/2006 15:50	1.01	0.25	24.68

7/7/2007 13:56	1.31	509.64	27.54
7/7/2007 13:56	1.31	489.58	27.55
7/7/2007 13:57	1.35	485.27	27.55
7/7/2007 13:57	1.36	497.36	27.54
7/7/2007 13:57	1.37	514.30	27.54
7/7/2007 13:57	1.44	529.90	27.57
7/7/2007 13:57	1.44	514.49	27.56
7/7/2007 13:57	1.44	465.74	27.55
7/7/2007 13:57	1.45	492.48	27.54
7/7/2007 13:57	1.45	492.61	27.54
7/7/2007 13:57	1.45	492.58	27.54
7/7/2007 13:57	1.40	408.86	27.54
7/7/2007 13:57	1.39	340.39	27.54
7/7/2007 13:57	1.39	509.91	27.53
7/7/2007 13:57	1.39	480.88	27.54
7/7/2007 13:57	1.39	524.22	27.53
7/7/2007 13:57	1.40	529.29	27.53
7/7/2007 13:57	1.36	539.05	27.53
7/7/2007 13:57	1.36	519.10	27.52
7/7/2007 13:57	1.34	505.26	27.52
7/7/2007 13:58	1.29	482.03	27.52
7/7/2007 13:58	1.28	473.71	27.51
7/7/2007 13:58	1.28	520.82	27.51
7/7/2007 13:58	1.26	501.56	27.51
7/7/2007 13:58	1.26	498.77	27.51
7/7/2007 13:58	1.26	506.86	27.51
7/7/2007 13:58	1.21	508.08	27.51
7/7/2007 13:58	1.20	486.53	27.50
7/7/2007 13:58	1.20	502.62	27.50
7/7/2007 13:58	1.21	494.12	27.51
7/7/2007 13:58	1.22	500.95	27.50
7/7/2007 13:58	1.22	505.75	27.50
7/7/2007 13:58	1.29	525.93	27.50
7/7/2007 13:58	1.30	487.25	27.50
7/7/2007 13:58	1.30	505.68	27.49
7/7/2007 13:58	1.32	509.00	27.50
7/7/2007 13:58	1.33	496.10	27.50
7/7/2007 13:58	1.34	496.22	27.50
7/7/2007 13:59	1.24	499.42	27.50
7/7/2007 13:59	1.25	485.27	27.50
7/7/2007 13:59	1.24	497.47	27.50
7/7/2007 13:59	1.26	479.09	27.50
7/7/2007 13:59	1.25	498.96	27.49
7/7/2007 13:59	1.23	494.54	27.49
7/7/2007 13:59	1.14	487.59	27.50
7/7/2007 13:59	1.14	485.42	27.49
7/7/2007 13:59	1.15	499.84	27.49
7/7/2007 13:59	1.06	487.59	27.49
7/7/2007 13:59	1.04	506.90	27.49
7/7/2007 13:59	1.03	490.57	27.48
7/7/2007 13:59	1.04	480.73	27.50
7/7/2007 13:59	1.04	494.65	27.48
7/7/2007 13:59	1.05	506.10	27.49
7/7/2007 13:59	1.00	25.63	27.50
7/7/2007 13:59	1.00	24.53	27.50
7/7/2007 13:59	1.00	24.45	27.50
7/7/2007 14:00	1.00	0.24	27.55
7/7/2007 14:00	1.00	0.24	27.56
7/7/2007 14:00	1.00	0.24	27.57
7/7/2007 14:00	1.00	0.24	27.62
7/7/2007 14:00	1.00	0.25	27.61
7/7/2007 14:00	1.00	0.24	27.59
7/7/2007 14:00	1.00	0.24	27.67
7/7/2007 14:00	1.00	0.24	27.67
7/7/2007 14:00	1.00	0.25	27.70

4/12/2006 15:50	1.01	0.24	24.70	7/7/2007 14:00	1.00	0.25	27.82
4/12/2006 15:50	1.01	0.24	24.70	7/7/2007 14:00	1.00	0.24	27.82
4/12/2006 15:50	1.01	0.24	24.70	7/7/2007 14:00	1.00	0.24	27.84
4/12/2006 15:50	1.01	0.24	24.72	7/7/2007 14:00	1.00	0.25	27.89
4/12/2006 15:50	1.01	0.24	24.72	7/7/2007 14:00	1.00	0.24	27.86
4/12/2006 15:50	1.01	0.23	24.72	7/7/2007 14:00	1.00	0.24	27.87
4/12/2006 15:50	1.01	0.24	24.75	7/7/2007 14:00	1.00	0.24	27.88
4/12/2006 15:50	1.01	0.24	24.75	7/7/2007 14:00	1.00	0.24	27.88
4/12/2006 15:50	1.01	0.25	24.75	7/7/2007 14:00	1.00	0.24	27.89
4/12/2006 15:51	1.01	0.24	24.78	7/7/2007 14:01	1.00	0.24	27.84
4/12/2006 15:51	1.01	0.24	24.78	7/7/2007 14:01	1.00	0.24	27.82
4/12/2006 15:51	1.01	0.24	24.77	7/7/2007 14:01	1.00	0.24	27.82
4/12/2006 15:51	1.01	0.24	24.79	7/7/2007 14:01	1.00	0.25	27.84
4/12/2006 15:51	1.01	0.24	24.78	7/7/2007 14:01	1.00	0.24	27.84
4/12/2006 15:51	1.01	0.24	24.78	7/7/2007 14:01	1.00	0.25	27.84
4/12/2006 15:51	1.01	0.24	24.78	7/7/2007 14:01	1.00	0.23	27.92
4/12/2006 15:51	1.01	0.24	24.78	7/7/2007 14:01	1.00	0.23	27.91
4/12/2006 15:51	1.01	0.24	24.77	7/7/2007 14:01	1.00	0.25	27.93
4/12/2006 15:51	1.01	0.24	24.80	7/7/2007 14:01	1.00	0.24	28.00
4/12/2006 15:51	1.01	0.24	24.79	7/7/2007 14:01	1.00	0.24	28.01
4/12/2006 15:51	1.01	0.24	24.79	7/7/2007 14:01	1.00	0.24	28.03
4/12/2006 15:51	1.01	0.24	24.82	7/7/2007 14:01	1.00	0.24	28.15
4/12/2006 15:51	1.01	0.24	24.81	7/7/2007 14:01	1.00	0.25	28.15
4/12/2006 15:51	1.01	0.24	24.80	7/7/2007 14:01	1.00	0.24	28.17
4/12/2006 15:51	1.01	0.24	24.83	7/7/2007 14:01	1.00	0.24	28.20
4/12/2006 15:51	1.01	0.24	24.82	7/7/2007 14:01	1.00	0.24	28.19
4/12/2006 15:51	1.01	0.24	24.82	7/7/2007 14:01	1.00	0.24	28.18
4/12/2006 15:52	1.01	0.24	24.84	7/7/2007 14:02	1.00	0.24	28.19
4/12/2006 15:52	1.01	0.25	24.83	7/7/2007 14:02	1.00	0.25	28.18
4/12/2006 15:52	1.01	0.24	24.83	7/7/2007 14:02	1.00	0.24	28.17
4/12/2006 15:52	1.01	0.24	24.84	7/7/2007 14:02	1.00	0.24	28.13
4/12/2006 15:52	1.01	0.24	24.83	7/7/2007 14:02	1.00	0.25	28.12
4/12/2006 15:52	1.01	0.24	24.83	7/7/2007 14:02	1.00	0.24	28.12
4/12/2006 15:52	1.01	0.24	24.83	7/7/2007 14:02	1.00	0.24	28.17
4/12/2006 15:52	1.01	0.24	24.83	7/7/2007 14:02	1.00	0.24	28.18
4/12/2006 15:52	1.01	0.24	24.82	7/7/2007 14:02	1.00	0.24	28.19
4/12/2006 15:52	1.01	0.24	24.83	7/7/2007 14:02	1.00	0.24	28.25
4/12/2006 15:52	1.01	0.25	24.83	7/7/2007 14:02	1.00	0.25	28.23
4/12/2006 15:52	1.01	0.24	24.82	7/7/2007 14:02	1.00	0.24	28.23
4/12/2006 15:52	1.01	0.24	24.83	7/7/2007 14:02	1.00	0.24	28.28
4/12/2006 15:52	1.01	0.24	24.82	7/7/2007 14:02	1.00	0.24	28.27
4/12/2006 15:52	1.01	0.24	24.81	7/7/2007 14:02	1.00	0.24	28.28
4/12/2006 15:52	1.01	0.24	24.81	7/7/2007 14:02	1.00	0.24	28.28
4/12/2006 15:52	1.01	0.24	24.80	7/7/2007 14:02	1.00	0.24	28.26
4/12/2006 15:52	1.01	0.24	24.79	7/7/2007 14:02	1.00	0.24	28.26
4/12/2006 15:53	1.01	0.25	24.80	7/7/2007 14:03	1.00	0.24	28.27
4/12/2006 15:53	1.01	0.24	24.80	7/7/2007 14:03	1.00	0.24	28.26
4/12/2006 15:53	1.01	0.23	24.79	7/7/2007 14:03	1.00	0.24	28.25
4/12/2006 15:53	1.01	0.24	24.80	7/7/2007 14:03	1.00	0.24	28.29
4/12/2006 15:53	1.01	0.24	24.79	7/7/2007 14:03	1.00	0.24	28.28
4/12/2006 15:53	1.01	0.24	24.79	7/7/2007 14:03	1.00	0.25	28.30
4/12/2006 15:53	1.01	0.24	24.81	7/7/2007 14:03	1.00	0.24	28.39
4/12/2006 15:53	1.01	0.24	24.80	7/7/2007 14:03	1.00	0.24	28.38
4/12/2006 15:53	1.01	0.24	24.80	7/7/2007 14:03	1.00	0.23	28.39
4/12/2006 15:53	1.01	0.24	24.81	7/7/2007 14:03	1.00	0.24	28.38
4/12/2006 15:53	1.01	0.24	24.80	7/7/2007 14:03	1.00	0.24	28.38
4/12/2006 15:53	1.01	0.24	24.80	7/7/2007 14:03	1.00	0.24	28.40
4/12/2006 15:53	1.01	0.23	24.82	7/7/2007 14:03	1.00	0.24	28.50
4/12/2006 15:53	1.01	0.25	24.82	7/7/2007 14:03	1.00	0.24	28.51
4/12/2006 15:53	1.01	0.24	24.81	7/7/2007 14:03	1.00	0.24	28.52
4/12/2006 15:53	1.01	0.24	24.83	7/7/2007 14:03	1.00	0.24	28.56
4/12/2006 15:53	1.01	0.23	24.83	7/7/2007 14:03	1.00	0.24	28.53
4/12/2006 15:53	1.01	0.24	24.82	7/7/2007 14:03	1.00	0.24	28.53
4/12/2006 15:54	1.01	0.24	24.83	7/7/2007 14:04	1.00	0.24	28.59
4/12/2006 15:54	1.01	0.25	24.83	7/7/2007 14:04	1.00	0.24	28.59

4/12/2006 15:54	1.01	0.24	24.83	7/7/2007 14:04	1.00	0.24	28.60
4/12/2006 15:54	1.01	0.24	24.85	7/7/2007 14:04	1.00	0.24	28.67
4/12/2006 15:54	1.01	0.24	24.84	7/7/2007 14:04	1.00	0.24	28.66
4/12/2006 15:54	1.01	0.25	24.84	7/7/2007 14:04	1.00	0.24	28.65
4/12/2006 15:54	1.01	0.24	24.85	7/7/2007 14:04	1.00	0.24	28.65
4/12/2006 15:54	1.01	0.23	24.84	7/7/2007 14:04	1.00	0.25	28.63
4/12/2006 15:54	1.01	0.24	24.84	7/7/2007 14:04	1.00	0.24	28.63
4/12/2006 15:54	1.01	0.24	24.84	7/7/2007 14:04	1.00	0.24	28.61
4/12/2006 15:54	1.01	0.25	24.83	7/7/2007 14:04	1.00	0.24	28.61
4/12/2006 15:54	1.01	0.24	24.82	7/7/2007 14:04	1.00	0.25	28.61
4/12/2006 15:54	1.01	0.25	24.83	7/7/2007 14:04	1.00	0.24	28.78
4/12/2006 15:54	1.01	0.24	24.83	7/7/2007 14:04	1.00	0.24	28.78
4/12/2006 15:54	1.01	0.25	24.82	7/7/2007 14:04	1.00	0.25	28.78
4/12/2006 15:54	1.01	0.24	24.80	7/7/2007 14:04	1.00	0.24	28.88
4/12/2006 15:54	1.01	0.24	24.79	7/7/2007 14:04	1.00	0.25	28.89
4/12/2006 15:54	1.01	0.24	24.78	7/7/2007 14:04	1.00	0.24	28.91
4/12/2006 15:55	1.01	0.25	24.76	7/7/2007 14:05	1.00	0.24	28.95
4/12/2006 15:55	1.01	0.24	24.75	7/7/2007 14:05	1.00	0.24	28.94
4/12/2006 15:55	1.01	0.24	24.75	7/7/2007 14:05	1.00	0.25	28.92
4/12/2006 15:55	1.01	0.24	24.77	7/7/2007 14:05	1.01	17.12	27.62
4/12/2006 15:55	1.01	0.24	24.76	7/7/2007 14:05	1.03	24.63	27.57
4/12/2006 15:55	1.01	0.24	24.76	7/7/2007 14:05	1.04	24.63	27.56
4/12/2006 15:55	1.01	0.24	24.79	7/7/2007 14:05	1.05	624.31	27.51
4/12/2006 15:55	1.01	0.24	24.78	7/7/2007 14:05	1.05	611.72	27.51
4/12/2006 15:55	1.01	0.24	24.79	7/7/2007 14:05	1.06	627.06	27.50
4/12/2006 15:55	1.01	0.23	24.83	7/7/2007 14:05	1.01	593.80	27.51
4/12/2006 15:55	1.01	0.24	24.83	7/7/2007 14:05	1.00	25.25	27.49
4/12/2006 15:55	1.01	0.25	24.83	7/7/2007 14:05	1.00	24.57	27.47
4/12/2006 15:55	1.04	123.18	24.72	7/7/2007 14:05	1.00	0.24	27.44
4/12/2006 15:55	1.08	123.13	24.71	7/7/2007 14:05	1.00	0.24	27.43
4/12/2006 15:55	1.14	123.16	24.71	7/7/2007 14:05	1.00	0.24	27.43
4/12/2006 15:55	1.56	142.97	24.71	7/7/2007 14:05	1.00	0.24	27.54
4/12/2006 15:55	1.62	140.09	24.70	7/7/2007 14:05	1.00	0.24	27.54
4/12/2006 15:55	1.70	146.39	24.70	7/7/2007 14:05	1.00	0.24	27.55
4/12/2006 15:56	2.24	147.88	24.71	7/7/2007 14:06	1.00	0.24	27.66
4/12/2006 15:56	2.32	139.91	24.70	7/7/2007 14:06	1.00	0.23	27.65
4/12/2006 15:56	2.39	145.90	24.70	7/7/2007 14:06	1.00	0.25	27.65
4/12/2006 15:56	2.99	139.00	24.71	7/7/2007 14:06	1.00	0.24	27.68
4/12/2006 15:56	3.06	141.36	24.70	7/7/2007 14:06	1.00	0.24	27.67
4/12/2006 15:56	3.13	141.20	24.69	7/7/2007 14:06	1.00	0.24	27.68
4/12/2006 15:56	3.67	139.98	24.71	7/7/2007 14:06	1.00	0.24	27.73
4/12/2006 15:56	3.75	146.68	24.70	7/7/2007 14:06	1.00	0.23	27.74
4/12/2006 15:56	3.82	141.60	24.70	7/7/2007 14:06	1.00	0.24	27.75
4/12/2006 15:56	4.09	150.43	24.69	7/7/2007 14:06	1.00	0.25	28.08
4/12/2006 15:56	4.06	130.05	24.68	7/7/2007 14:06	1.00	0.25	28.10
4/12/2006 15:56	4.08	139.35	24.69	7/7/2007 14:06	1.00	0.24	28.13
4/12/2006 15:56	4.21	144.91	24.69	7/7/2007 14:06	1.00	0.25	28.36
4/12/2006 15:56	4.21	143.80	24.68	7/7/2007 14:06	1.00	0.24	28.36
4/12/2006 15:56	4.21	141.27	24.69	7/7/2007 14:06	1.00	0.24	28.38
4/12/2006 15:56	4.20	148.46	24.69	7/7/2007 14:06	1.00	0.24	28.44
4/12/2006 15:56	4.20	147.61	24.68	7/7/2007 14:06	1.00	0.24	28.43
4/12/2006 15:56	4.20	139.26	24.69	7/7/2007 14:06	1.00	0.24	28.44
4/12/2006 15:57	4.19	143.85	24.69	7/7/2007 14:07	1.00	0.24	28.52
4/12/2006 15:57	4.19	140.69	24.69	7/7/2007 14:07	1.00	0.24	28.52
4/12/2006 15:57	4.19	144.63	24.69	7/7/2007 14:07	1.00	0.25	28.52
4/12/2006 15:57	4.15	153.85	24.69	7/7/2007 14:07	1.00	0.24	28.60
4/12/2006 15:57	4.15	141.06	24.69	7/7/2007 14:07	1.00	0.24	28.60
4/12/2006 15:57	4.15	144.76	24.69	7/7/2007 14:07	1.00	0.25	28.61
4/12/2006 15:57	4.13	139.11	24.69	7/7/2007 14:07	1.00	0.24	28.67
4/12/2006 15:57	4.12	144.37	24.69	7/7/2007 14:07	1.00	0.24	28.67
4/12/2006 15:57	4.12	140.55	24.69	7/7/2007 14:07	1.00	0.25	28.67
4/12/2006 15:57	4.10	132.55	24.69	7/7/2007 14:07	1.00	0.25	28.72
4/12/2006 15:57	4.09	139.05	24.69	7/7/2007 14:07	1.00	0.24	28.70
4/12/2006 15:57	4.08	136.80	24.69	7/7/2007 14:07	1.00	0.25	28.70
4/12/2006 15:57	4.05	142.94	24.69	7/7/2007 14:07	1.00	0.25	28.72

4/12/2006 15:57	4.05	132.81	24.69
4/12/2006 15:57	4.04	133.48	24.69
4/12/2006 15:57	3.93	139.99	24.69
4/12/2006 15:57	3.95	136.41	24.69
4/12/2006 15:57	3.96	133.48	24.69
4/12/2006 15:58	3.85	137.19	24.69
4/12/2006 15:58	3.86	135.50	24.68
4/12/2006 15:58	3.88	137.00	24.69
4/12/2006 15:58	3.89	156.84	24.69
4/12/2006 15:58	3.89	132.86	24.68
4/12/2006 15:58	3.90	139.82	24.69
4/12/2006 15:58	3.83	128.49	24.69
4/12/2006 15:58	3.83	133.93	24.68
4/12/2006 15:58	3.84	137.50	24.69
4/12/2006 15:58	3.77	136.21	24.68
4/12/2006 15:58	3.77	129.68	24.68
4/12/2006 15:58	3.77	131.59	24.68
4/12/2006 15:58	3.76	139.18	24.69
4/12/2006 15:58	3.76	138.31	24.68
4/12/2006 15:58	3.75	134.70	24.68
4/12/2006 15:58	3.61	133.56	24.69
4/12/2006 15:58	3.61	136.02	24.68
4/12/2006 15:58	3.60	133.57	24.68
4/12/2006 15:59	3.42	132.54	24.68
4/12/2006 15:59	3.41	132.46	24.68
4/12/2006 15:59	3.40	136.95	24.68
4/12/2006 15:59	3.14	128.88	24.68
4/12/2006 15:59	3.11	130.87	24.68
4/12/2006 15:59	3.10	131.74	24.68
4/12/2006 15:59	2.81	134.21	24.69
4/12/2006 15:59	2.79	127.93	24.68
4/12/2006 15:59	2.76	130.06	24.68
4/12/2006 15:59	2.46	127.97	24.69
4/12/2006 15:59	2.45	133.00	24.68
4/12/2006 15:59	2.44	132.44	24.68
4/12/2006 15:59	2.32	132.42	24.69
4/12/2006 15:59	2.33	128.12	24.68
4/12/2006 15:59	2.34	128.15	24.68
4/12/2006 15:59	2.33	132.68	24.69
4/12/2006 15:59	2.35	135.97	24.68
4/12/2006 15:59	2.37	129.49	24.68
4/12/2006 16:00	2.39	128.87	24.69
4/12/2006 16:00	2.40	128.08	24.69
4/12/2006 16:00	2.41	131.95	24.69
4/12/2006 16:00	2.35	130.82	24.69
4/12/2006 16:00	2.36	130.74	24.69
4/12/2006 16:00	2.36	134.06	24.68
4/12/2006 16:00	2.24	129.82	24.68
4/12/2006 16:00	2.24	133.09	24.68
4/12/2006 16:00	2.24	127.80	24.68
4/12/2006 16:00	2.12	132.32	24.69
4/12/2006 16:00	2.12	130.96	24.68
4/12/2006 16:00	2.13	131.00	24.68
4/12/2006 16:00	1.97	128.56	24.69
4/12/2006 16:00	1.96	129.59	24.68
4/12/2006 16:00	1.95	128.92	24.68
4/12/2006 16:00	1.77	130.07	24.69
4/12/2006 16:00	1.76	128.63	24.68
4/12/2006 16:00	1.75	129.51	24.68
4/12/2006 16:01	1.58	126.76	24.69
4/12/2006 16:01	1.57	127.10	24.68
4/12/2006 16:01	1.56	127.33	24.68
4/12/2006 16:01	1.46	127.35	24.68
4/12/2006 16:01	1.46	128.37	24.68
4/12/2006 16:01	1.46	127.23	24.68

7/7/2007 14:07	1.00	0.24	28.72
7/7/2007 14:07	1.00	0.24	28.72
7/7/2007 14:07	1.00	0.24	28.78
7/7/2007 14:07	1.00	0.24	28.77
7/7/2007 14:07	1.00	0.24	28.77
7/7/2007 14:08	1.00	0.24	28.82
7/7/2007 14:08	1.00	0.24	28.81
7/7/2007 14:08	1.00	0.24	28.81
7/7/2007 14:08	1.00	0.24	28.86
7/7/2007 14:08	1.00	0.24	28.84
7/7/2007 14:08	1.00	0.24	28.85
7/7/2007 14:08	1.00	0.24	28.97
7/7/2007 14:08	1.00	0.24	28.96
7/7/2007 14:08	1.00	0.24	28.96
7/7/2007 14:08	1.00	0.25	29.03
7/7/2007 14:08	1.00	0.25	29.01
7/7/2007 14:08	1.00	0.24	29.02
7/7/2007 14:08	1.00	0.24	29.08
7/7/2007 14:08	1.00	0.24	29.07
7/7/2007 14:08	1.00	0.25	29.08
7/7/2007 14:08	1.00	0.24	29.16
7/7/2007 14:08	1.00	0.24	29.16
7/7/2007 14:08	1.00	0.24	29.16
7/7/2007 14:09	1.00	0.24	29.24
7/7/2007 14:09	1.00	0.24	29.21
7/7/2007 14:09	1.00	0.24	29.20
7/7/2007 14:09	1.00	0.24	29.11
7/7/2007 14:09	1.00	0.24	29.10
7/7/2007 14:09	1.00	0.23	29.10
7/7/2007 14:09	1.00	0.24	29.12
7/7/2007 14:09	1.00	0.24	29.10
7/7/2007 14:09	1.00	0.25	29.10
7/7/2007 14:09	1.00	0.24	29.11
7/7/2007 14:09	1.00	0.25	29.09
7/7/2007 14:09	1.00	0.24	29.08
7/7/2007 14:09	1.00	0.24	28.87
7/7/2007 14:09	1.00	0.24	28.85
7/7/2007 14:09	1.00	0.25	28.84
7/7/2007 14:09	1.00	0.24	28.75
7/7/2007 14:09	1.00	0.25	28.73
7/7/2007 14:09	1.00	0.24	28.72
7/7/2007 14:10	1.00	0.24	28.65
7/7/2007 14:10	1.00	0.24	28.62
7/7/2007 14:10	1.00	0.25	28.61
7/7/2007 14:10	1.00	0.24	28.61
7/7/2007 14:10	1.00	0.24	28.61
7/7/2007 14:10	1.00	0.24	28.61
7/7/2007 14:10	1.00	0.24	28.52
7/7/2007 14:10	1.00	0.25	28.49
7/7/2007 14:10	1.00	0.24	28.48
7/7/2007 14:10	1.00	0.24	28.37
7/7/2007 14:10	1.00	0.24	28.36
7/7/2007 14:10	1.00	0.25	28.38
7/7/2007 14:10	1.00	0.24	28.54
7/7/2007 14:10	1.00	0.24	28.54
7/7/2007 14:10	1.00	0.24	28.55
7/7/2007 14:10	1.00	0.24	28.63
7/7/2007 14:10	1.00	0.24	28.62
7/7/2007 14:10	1.00	0.24	28.63
7/7/2007 14:11	1.00	0.24	28.69
7/7/2007 14:11	1.00	0.24	28.68
7/7/2007 14:11	1.00	0.24	28.69
7/7/2007 14:11	1.00	0.24	28.75
7/7/2007 14:11	1.00	0.24	28.74
7/7/2007 14:11	1.00	0.25	28.75

4/12/2006 16:01	1.39	126.82	24.69	7/7/2007 14:11	1.00	0.24	28.79
4/12/2006 16:01	1.39	128.88	24.68	7/7/2007 14:11	1.00	0.24	28.79
4/12/2006 16:01	1.39	127.92	24.68	7/7/2007 14:11	1.00	0.24	28.79
4/12/2006 16:01	1.32	126.61	24.69	7/7/2007 14:11	1.00	0.25	28.84
4/12/2006 16:01	1.33	129.20	24.68	7/7/2007 14:11	1.00	0.24	28.83
4/12/2006 16:01	1.33	128.78	24.68	7/7/2007 14:11	1.00	0.24	28.84
4/12/2006 16:01	1.28	130.21	24.69	7/7/2007 14:11	1.00	0.24	28.91
4/12/2006 16:01	1.29	126.43	24.68	7/7/2007 14:11	1.00	0.23	28.90
4/12/2006 16:01	1.29	131.21	24.68	7/7/2007 14:11	1.00	0.25	28.91
4/12/2006 16:01	1.20	125.01	24.69	7/7/2007 14:11	1.00	0.24	28.97
4/12/2006 16:01	1.20	127.70	24.68	7/7/2007 14:11	1.00	0.25	28.96
4/12/2006 16:01	1.20	126.93	24.68	7/7/2007 14:11	1.00	0.24	28.97
4/12/2006 16:02	1.09	127.16	24.68	7/7/2007 14:12	1.00	0.24	29.02
4/12/2006 16:02	1.10	130.09	24.68	7/7/2007 14:12	1.00	0.25	29.01
4/12/2006 16:02	1.10	126.79	24.68	7/7/2007 14:12	1.00	0.24	29.01
4/12/2006 16:02	1.03	0.24	24.69	7/7/2007 14:12	1.00	0.24	29.07
4/12/2006 16:02	1.03	0.24	24.68	7/7/2007 14:12	1.00	0.24	29.06
4/12/2006 16:02	1.03	0.24	24.68	7/7/2007 14:12	1.00	0.24	29.06
4/12/2006 16:02	1.01	0.23	24.61	7/7/2007 14:12	1.00	0.25	29.11
4/12/2006 16:02	1.01	0.24	24.58	7/7/2007 14:12	1.00	0.25	29.10
4/12/2006 16:02	1.01	0.24	24.57	7/7/2007 14:12	1.00	0.25	29.10
4/12/2006 16:02	1.01	0.24	24.50	7/7/2007 14:12	1.00	0.24	29.15
4/12/2006 16:02	1.01	0.24	24.48	7/7/2007 14:12	1.00	0.24	29.14
4/12/2006 16:02	1.01	0.24	24.46	7/7/2007 14:12	1.00	0.24	29.15
4/12/2006 16:02	1.01	0.24	24.39	7/7/2007 14:12	1.00	0.24	29.20
4/12/2006 16:02	1.01	0.24	24.38	7/7/2007 14:12	1.00	0.23	29.19
4/12/2006 16:02	1.01	0.24	24.36	7/7/2007 14:12	1.00	0.25	29.20
4/12/2006 16:02	1.01	0.25	24.37	7/7/2007 14:12	1.00	0.24	29.22
4/12/2006 16:02	1.01	0.25	24.37	7/7/2007 14:12	1.00	0.25	29.21
4/12/2006 16:02	1.01	0.25	24.38	7/7/2007 14:12	1.00	0.24	29.22
4/12/2006 16:03	1.01	0.24	24.39	7/7/2007 14:13	1.00	0.25	29.26
4/12/2006 16:03	1.01	0.24	24.38	7/7/2007 14:13	1.00	0.24	29.26
4/12/2006 16:03	1.01	0.25	24.38	7/7/2007 14:13	1.00	0.24	29.26
4/12/2006 16:03	1.01	0.24	24.39	7/7/2007 14:13	1.00	0.24	29.29
4/12/2006 16:03	1.01	0.24	24.37	7/7/2007 14:13	1.00	0.24	29.28
4/12/2006 16:03	1.01	0.25	24.37	7/7/2007 14:13	1.00	0.24	29.28
4/12/2006 16:03	1.01	0.24	24.40	7/7/2007 14:13	1.00	0.24	29.29
4/12/2006 16:03	1.01	0.24	24.39	7/7/2007 14:13	1.00	0.25	29.28
4/12/2006 16:03	1.01	0.24	24.39	7/7/2007 14:13	1.00	0.25	29.29
4/12/2006 16:03	1.01	0.24	24.42	7/7/2007 14:13	1.00	0.25	29.35
4/12/2006 16:03	1.01	0.23	24.41	7/7/2007 14:13	1.00	0.25	29.35
4/12/2006 16:03	1.01	0.24	24.41	7/7/2007 14:13	1.00	0.24	29.36
4/12/2006 16:03	1.01	0.23	24.45	7/7/2007 14:13	1.00	0.24	29.40
4/12/2006 16:03	1.01	0.24	24.44	7/7/2007 14:13	1.00	0.25	29.40
4/12/2006 16:03	1.01	0.24	24.44	7/7/2007 14:13	1.00	0.24	29.40
4/12/2006 16:03	1.01	0.24	24.46	7/7/2007 14:13	1.00	0.25	29.43
4/12/2006 16:03	1.01	0.25	24.44	7/7/2007 14:13	1.00	0.24	29.42
4/12/2006 16:03	1.01	0.25	24.45	7/7/2007 14:13	1.00	0.25	29.41
4/12/2006 16:04	1.10	24.63	24.66	7/7/2007 14:14	1.00	0.24	29.44
4/12/2006 16:04	1.16	24.63	24.66	7/7/2007 14:14	1.00	0.25	29.43
4/12/2006 16:04	1.23	24.63	24.67	7/7/2007 14:14	1.00	0.25	29.43
4/12/2006 16:04	1.78	140.58	24.68	7/7/2007 14:14	1.00	0.24	29.44
4/12/2006 16:04	1.85	140.85	24.68	7/7/2007 14:14	1.00	0.24	29.43
4/12/2006 16:04	1.92	147.10	24.67	7/7/2007 14:14	1.00	0.24	29.43
4/12/2006 16:04	2.35	147.46	24.68	7/7/2007 14:14	1.00	0.25	29.41
4/12/2006 16:04	2.41	141.19	24.67	7/7/2007 14:14	1.00	0.25	29.41
4/12/2006 16:04	2.44	144.42	24.67	7/7/2007 14:14	1.00	0.24	29.41
4/12/2006 16:04	2.50	136.33	24.68	7/7/2007 14:14	1.00	0.24	29.47
4/12/2006 16:04	2.50	144.29	24.68	7/7/2007 14:14	1.00	0.24	29.47
4/12/2006 16:04	2.49	138.49	24.67	7/7/2007 14:14	1.00	0.24	29.48
4/12/2006 16:04	2.48	135.88	24.68	7/7/2007 14:14	1.00	0.24	29.53
4/12/2006 16:04	2.46	144.01	24.67	7/7/2007 14:14	1.00	0.24	29.51
4/12/2006 16:04	2.44	141.90	24.68	7/7/2007 14:14	1.00	0.23	29.51
4/12/2006 16:04	1.92	137.99	24.68	7/7/2007 14:14	1.00	0.24	29.54
4/12/2006 16:04	1.88	151.88	24.68	7/7/2007 14:14	1.00	0.25	29.53

4/12/2006 16:04	1.79	138.64	24.68
4/12/2006 16:05	1.38	148.41	24.68
4/12/2006 16:05	1.31	145.97	24.67
4/12/2006 16:05	1.25	135.51	24.67
4/12/2006 16:05	1.02	135.82	24.68
4/12/2006 16:05	1.01	5.78	24.67
4/12/2006 16:05	1.01	4.83	24.62
4/12/2006 16:05	1.01	0.24	24.56
4/12/2006 16:05	1.01	0.25	24.55
4/12/2006 16:05	1.01	0.25	24.55
4/12/2006 16:05	1.01	0.24	24.55
4/12/2006 16:05	1.01	0.24	24.54
4/12/2006 16:05	1.01	0.25	24.54
4/12/2006 16:05	1.01	0.24	24.52
4/12/2006 16:05	1.01	0.25	24.51
4/12/2006 16:05	1.01	0.24	24.51
4/12/2006 16:05	1.01	0.24	24.51
4/12/2006 16:05	1.01	0.25	24.50
4/12/2006 16:05	1.01	0.24	24.50
4/12/2006 16:06	1.01	0.25	24.47
4/12/2006 16:06	1.01	0.24	24.47
4/12/2006 16:06	1.03	1.01	24.58
4/12/2006 16:06	1.11	121.28	24.71
4/12/2006 16:06	1.10	122.44	24.70
4/12/2006 16:06	1.11	118.78	24.70
4/12/2006 16:06	1.01	4.81	24.71
4/12/2006 16:06	1.01	4.79	24.65
4/12/2006 16:06	1.01	4.79	24.64
4/12/2006 16:06	1.01	0.24	24.59
4/12/2006 16:06	1.01	0.25	24.58
4/12/2006 16:06	1.01	0.24	24.57
4/12/2006 16:06	1.01	0.24	24.54
4/12/2006 16:06	1.01	0.24	24.53
4/12/2006 16:06	1.01	0.24	24.53
4/12/2006 16:06	1.01	0.24	24.41
4/12/2006 16:06	1.01	0.24	24.38
4/12/2006 16:06	1.01	0.24	24.36
4/12/2006 16:07	1.01	0.24	24.29
4/12/2006 16:07	1.01	0.24	24.27
4/12/2006 16:07	1.01	0.24	24.27
4/12/2006 16:07	1.01	0.24	24.25
4/12/2006 16:07	1.01	0.24	24.24
4/12/2006 16:07	1.01	0.25	24.23
4/12/2006 16:07	1.01	0.24	24.26
4/12/2006 16:07	1.01	0.24	24.25
4/12/2006 16:07	1.01	0.25	24.25
4/12/2006 16:07	1.01	0.24	24.28
4/12/2006 16:07	1.01	0.24	24.27
4/12/2006 16:07	1.01	0.23	24.28
4/12/2006 16:07	1.01	0.24	24.31
4/12/2006 16:07	1.01	0.23	24.30
4/12/2006 16:07	1.01	0.24	24.31
4/12/2006 16:07	1.01	0.24	24.33
4/12/2006 16:07	1.01	0.24	24.32
4/12/2006 16:07	1.01	0.24	24.32
4/12/2006 16:08	1.01	0.24	24.30
4/12/2006 16:08	1.01	0.23	24.29
4/12/2006 16:08	1.01	0.24	24.29
4/12/2006 16:08	1.01	0.25	24.30
4/12/2006 16:08	1.01	0.24	24.28
4/12/2006 16:08	1.01	0.24	24.28
4/12/2006 16:08	1.01	0.24	24.27
4/12/2006 16:08	1.01	0.25	24.26
4/12/2006 16:08	1.01	0.24	24.27
4/12/2006 16:08	1.01	0.24	24.29

7/7/2007 14:14	1.00	0.24	29.53
7/7/2007 14:15	1.00	0.25	29.57
7/7/2007 14:15	1.00	0.25	29.56
7/7/2007 14:15	1.00	0.24	29.57
7/7/2007 14:15	1.00	0.24	29.57
7/7/2007 14:15	1.00	0.25	29.56
7/7/2007 14:15	1.00	0.24	29.57
7/7/2007 14:15	1.00	0.24	29.58
7/7/2007 14:15	1.00	0.24	29.57
7/7/2007 14:15	1.00	0.24	29.57
7/7/2007 14:15	1.00	0.25	29.58
7/7/2007 14:15	1.00	0.24	29.58
7/7/2007 14:15	1.00	0.24	29.60
7/7/2007 14:15	1.00	0.25	29.63
7/7/2007 14:15	1.00	0.25	29.62
7/7/2007 14:15	1.00	0.25	29.62
7/7/2007 14:15	1.00	0.24	29.64
7/7/2007 14:15	1.00	0.24	29.63
7/7/2007 14:15	1.00	0.24	29.62
7/7/2007 14:16	1.00	0.25	29.61
7/7/2007 14:16	1.00	0.24	29.58
7/7/2007 14:16	1.00	0.24	29.57
7/7/2007 14:16	1.00	0.24	29.59
7/7/2007 14:16	1.00	0.25	29.58
7/7/2007 14:16	1.00	0.25	29.58
7/7/2007 14:16	1.00	0.24	29.61
7/7/2007 14:16	1.00	0.24	29.60
7/7/2007 14:16	1.00	0.24	29.61
7/7/2007 14:16	1.00	0.24	29.63
7/7/2007 14:16	1.00	0.24	29.63
7/7/2007 14:16	1.00	0.24	29.63
7/7/2007 14:16	1.00	0.24	29.67
7/7/2007 14:16	1.00	0.24	29.67
7/7/2007 14:16	1.00	0.23	29.67
7/7/2007 14:16	1.00	0.24	29.71
7/7/2007 14:16	1.00	0.25	29.70
7/7/2007 14:16	1.00	0.24	29.69
7/7/2007 14:17	1.00	0.25	29.70
7/7/2007 14:17	1.00	0.25	29.69
7/7/2007 14:17	1.00	0.24	29.69
7/7/2007 14:17	1.00	0.24	29.73
7/7/2007 14:17	1.00	0.24	29.72
7/7/2007 14:17	1.00	0.25	29.71
7/7/2007 14:17	1.00	0.23	29.75
7/7/2007 14:17	1.00	0.24	29.73
7/7/2007 14:17	1.00	0.24	29.73
7/7/2007 14:17	1.00	0.24	29.75
7/7/2007 14:17	1.00	0.24	29.74
7/7/2007 14:17	1.00	0.24	29.75
7/7/2007 14:17	1.00	0.23	29.79
7/7/2007 14:17	1.00	0.24	29.78
7/7/2007 14:17	1.00	0.24	29.78
7/7/2007 14:17	1.00	0.23	29.79
7/7/2007 14:17	1.00	0.24	29.79
7/7/2007 14:17	1.00	0.25	29.79
7/7/2007 14:18	1.00	0.24	29.82
7/7/2007 14:18	1.00	0.24	29.81
7/7/2007 14:18	1.00	0.24	29.81

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4/12/2006 16:08	1.01	0.24	24.28
4/12/2006 16:08	1.19	99.55	24.98
4/12/2006 16:08	1.27	97.66	25.00
4/12/2006 16:08	1.35	104.69	24.99
4/12/2006 16:08	1.86	107.78	24.88
4/12/2006 16:08	1.92	99.52	24.88
4/12/2006 16:08	1.98	104.19	24.88
4/12/2006 16:09	2.52	99.67	24.89
4/12/2006 16:09	2.59	98.27	24.88
4/12/2006 16:09	2.66	95.40	24.88
4/12/2006 16:09	2.85	512.70	24.88
4/12/2006 16:09	2.83	154.91	24.88
4/12/2006 16:09	2.79	123.02	24.88
4/12/2006 16:09	2.79	163.24	24.89
4/12/2006 16:09	2.79	142.58	24.88
4/12/2006 16:09	2.79	149.55	24.88
4/12/2006 16:09	2.74	110.88	24.89
4/12/2006 16:09	2.69	113.33	24.88
4/12/2006 16:09	2.67	124.99	24.88
4/12/2006 16:09	2.65	110.38	24.89
4/12/2006 16:09	2.57	108.27	24.88
4/12/2006 16:09	2.56	107.41	24.88
4/12/2006 16:09	2.52	114.54	24.89
4/12/2006 16:09	2.43	121.99	24.88
4/12/2006 16:09	2.43	111.78	24.88
4/12/2006 16:10	2.36	110.60	24.89
4/12/2006 16:10	2.34	113.47	24.88
4/12/2006 16:10	2.33	109.56	24.88
4/12/2006 16:10	2.31	103.67	24.88
4/12/2006 16:10	2.25	107.52	24.88
4/12/2006 16:10	2.22	110.04	24.88
4/12/2006 16:10	2.15	99.95	24.88
4/12/2006 16:10	2.12	106.91	24.88
4/12/2006 16:10	2.11	103.68	24.89
4/12/2006 16:10	2.05	96.54	24.89
4/12/2006 16:10	2.03	99.66	24.89
4/12/2006 16:10	2.01	100.59	24.89
4/12/2006 16:10	1.97	103.53	24.90
4/12/2006 16:10	1.97	103.43	24.89
4/12/2006 16:10	1.97	99.45	24.89
4/12/2006 16:10	1.93	101.59	24.91
4/12/2006 16:10	1.94	100.54	24.91
4/12/2006 16:10	1.93	97.07	24.91
4/12/2006 16:11	1.89	103.99	24.90
4/12/2006 16:11	1.90	99.56	24.91
4/12/2006 16:11	1.90	101.73	24.91
4/12/2006 16:11	1.83	105.92	24.90
4/12/2006 16:11	1.83	103.53	24.91
4/12/2006 16:11	1.83	107.10	24.91
4/12/2006 16:11	1.79	104.57	24.91
4/12/2006 16:11	1.78	102.79	24.91
4/12/2006 16:11	1.80	101.62	24.91
4/12/2006 16:11	1.72	101.55	24.91
4/12/2006 16:11	1.74	104.73	24.91
4/12/2006 16:11	1.74	101.68	24.90
4/12/2006 16:11	1.65	103.98	24.91
4/12/2006 16:11	1.64	102.76	24.91
4/12/2006 16:11	1.65	101.23	24.92
4/12/2006 16:11	1.57	100.67	24.98
4/12/2006 16:11	1.56	97.73	24.98
4/12/2006 16:11	1.53	99.70	24.97
4/12/2006 16:12	1.52	102.75	24.97
4/12/2006 16:12	1.50	103.52	24.97
4/12/2006 16:12	1.47	100.31	24.96

4/12/2006 16:12	1.43	104.54	24.97
4/12/2006 16:12	1.39	109.38	24.97
4/12/2006 16:12	1.38	103.17	24.96
4/12/2006 16:12	1.36	101.67	24.97
4/12/2006 16:12	1.36	102.49	24.97
4/12/2006 16:12	1.36	101.60	24.97
4/12/2006 16:12	1.34	105.44	24.97
4/12/2006 16:12	1.32	99.12	24.96
4/12/2006 16:12	1.31	107.07	24.96
4/12/2006 16:12	1.31	103.58	24.94
4/12/2006 16:12	1.28	95.21	24.94
4/12/2006 16:12	1.24	95.68	24.96
4/12/2006 16:12	1.19	95.70	24.98
4/12/2006 16:12	1.19	95.72	24.98
4/12/2006 16:12	1.19	95.55	24.99
4/12/2006 16:13	1.06	97.59	24.96
4/12/2006 16:13	1.07	94.28	24.97
4/12/2006 16:13	1.07	92.13	24.97
4/12/2006 16:13	1.01	0.25	24.99
4/12/2006 16:13	1.01	0.24	24.95
4/12/2006 16:13	1.01	0.23	24.94
4/12/2006 16:13	1.01	0.24	24.81
4/12/2006 16:13	1.01	0.24	24.78
4/12/2006 16:13	1.01	0.23	24.78
4/12/2006 16:13	1.01	0.24	24.73
4/12/2006 16:13	1.01	0.24	24.72
4/12/2006 16:13	1.01	0.25	24.72
4/12/2006 16:13	1.01	0.24	24.74
4/12/2006 16:13	1.01	0.24	24.72
4/12/2006 16:13	1.01	0.24	24.71
4/12/2006 16:13	1.01	0.24	24.66
4/12/2006 16:13	1.01	0.24	24.65
4/12/2006 16:13	1.01	0.24	24.64
4/12/2006 16:14	1.01	0.24	24.62
4/12/2006 16:14	1.01	0.24	24.60
4/12/2006 16:14	1.01	0.25	24.60
4/12/2006 16:14	1.01	0.24	24.59
4/12/2006 16:14	1.01	0.24	24.58
4/12/2006 16:14	1.01	0.24	24.58
4/12/2006 16:14	1.01	0.24	24.60
4/12/2006 16:14	1.01	0.24	24.59
4/12/2006 16:14	1.01	0.24	24.59
4/12/2006 16:14	1.01	0.24	24.61
4/12/2006 16:14	1.01	0.24	24.60
4/12/2006 16:14	1.01	0.24	24.60
4/12/2006 16:14	1.01	0.24	24.59
4/12/2006 16:14	1.01	0.23	24.58
4/12/2006 16:14	1.01	0.24	24.58
4/12/2006 16:14	1.02	0.24	24.61
4/12/2006 16:14	1.06	2.33	25.08
4/12/2006 16:14	1.13	24.63	25.09
4/12/2006 16:15	1.60	105.48	24.93
4/12/2006 16:15	1.66	98.66	24.93
4/12/2006 16:15	1.73	101.15	24.93
4/12/2006 16:15	1.88	108.36	24.93
4/12/2006 16:15	1.88	104.27	24.93
4/12/2006 16:15	1.88	98.59	24.93
4/12/2006 16:15	1.83	101.53	24.92
4/12/2006 16:15	1.75	109.65	24.92
4/12/2006 16:15	1.66	101.80	24.92
4/12/2006 16:15	1.10	95.74	24.99
4/12/2006 16:15	1.03	26.11	25.05
4/12/2006 16:15	1.02	1.35	25.17
4/12/2006 16:15	1.01	0.25	25.19
4/12/2006 16:15	1.01	0.24	25.17

4/12/2006 16:15	1.01	0.24	25.15
4/12/2006 16:15	1.01	0.25	25.08
4/12/2006 16:15	1.01	0.24	25.06
4/12/2006 16:15	1.01	0.24	25.07
4/12/2006 16:16	1.01	0.24	25.08
4/12/2006 16:16	1.01	0.24	25.06
4/12/2006 16:16	1.01	0.24	25.06
4/12/2006 16:16	1.01	0.24	25.01
4/12/2006 16:16	1.01	0.24	24.99
4/12/2006 16:16	1.01	0.24	24.99
4/12/2006 16:16	1.01	0.24	25.00
4/12/2006 16:16	1.01	0.24	24.99
4/12/2006 16:16	1.01	0.25	24.98
4/12/2006 16:16	1.12	94.33	25.00
4/12/2006 16:16	1.12	107.40	25.00
4/12/2006 16:16	1.12	114.44	25.00
4/12/2006 16:16	1.13	106.62	24.99
4/12/2006 16:16	1.12	110.96	24.97
4/12/2006 16:16	1.08	116.64	24.97
4/12/2006 16:16	1.01	0.24	24.85
4/12/2006 16:16	1.01	0.24	24.83
4/12/2006 16:16	1.01	0.24	24.82
4/12/2006 16:17	1.01	0.24	24.81
4/12/2006 16:17	1.01	0.24	24.79
4/12/2006 16:17	1.01	0.24	24.79
4/12/2006 16:17	1.01	0.24	24.74
4/12/2006 16:17	1.01	0.25	24.72
4/12/2006 16:17	1.01	0.24	24.71
4/12/2006 16:17	1.01	0.25	24.73
4/12/2006 16:17	1.01	0.24	24.71
4/12/2006 16:17	1.01	0.24	24.71
4/12/2006 16:17	1.01	0.24	24.70
4/12/2006 16:17	1.01	0.23	24.69
4/12/2006 16:17	1.01	0.24	24.69
4/12/2006 16:17	1.01	0.24	24.67
4/12/2006 16:17	1.01	0.25	24.66
4/12/2006 16:17	1.01	0.24	24.66
4/12/2006 16:17	1.01	0.24	24.65
4/12/2006 16:17	1.01	0.23	24.63
4/12/2006 16:17	1.01	0.24	24.63
4/12/2006 16:18	1.01	0.24	24.60
4/12/2006 16:18	1.01	0.24	24.59
4/12/2006 16:18	1.01	0.24	24.58
4/12/2006 16:18	1.01	0.25	24.56
4/12/2006 16:18	1.01	0.24	24.55
4/12/2006 16:18	1.01	0.25	24.55
4/12/2006 16:18	1.01	0.23	24.52
4/12/2006 16:18	1.01	0.24	24.50
4/12/2006 16:18	1.01	0.24	24.49
4/12/2006 16:18	1.01	0.24	24.48
4/12/2006 16:18	1.01	0.24	24.46
4/12/2006 16:18	1.01	0.24	24.46
4/12/2006 16:18	1.01	0.24	24.51
4/12/2006 16:18	1.01	0.23	24.49
4/12/2006 16:18	1.01	0.23	24.49
4/12/2006 16:18	1.01	0.24	24.48
4/12/2006 16:18	1.01	0.24	24.47
4/12/2006 16:18	1.01	0.23	24.46
4/12/2006 16:19	1.01	0.24	24.47
4/12/2006 16:19	1.01	0.24	24.46
4/12/2006 16:19	1.01	0.24	24.46
4/12/2006 16:19	1.01	0.24	24.48
4/12/2006 16:19	1.01	0.24	24.47
4/12/2006 16:19	1.01	0.24	24.47
4/12/2006 16:19	1.01	0.24	24.49

4/12/2006 16:19	1.01	0.23	24.47
4/12/2006 16:19	1.01	0.24	24.47
4/12/2006 16:19	1.01	0.25	24.49
4/12/2006 16:19	1.01	0.25	24.47
4/12/2006 16:19	1.01	0.23	24.47
4/12/2006 16:19	1.03	24.62	24.59
4/12/2006 16:19	1.07	24.63	24.65
4/12/2006 16:19	1.12	24.63	24.66
4/12/2006 16:19	1.62	132.79	24.67
4/12/2006 16:19	1.66	141.82	24.66
4/12/2006 16:19	1.70	134.65	24.66
4/12/2006 16:20	2.08	132.84	24.67
4/12/2006 16:20	2.14	125.53	24.66
4/12/2006 16:20	2.19	126.28	24.66
4/12/2006 16:20	2.58	132.74	24.67
4/12/2006 16:20	2.64	131.13	24.66
4/12/2006 16:20	2.69	125.49	24.66
4/12/2006 16:20	3.04	132.10	24.67
4/12/2006 16:20	3.07	137.79	24.66
4/12/2006 16:20	3.11	140.60	24.66
4/12/2006 16:20	3.29	140.67	24.67
4/12/2006 16:20	3.33	144.55	24.66
4/12/2006 16:20	3.39	142.70	24.66
4/12/2006 16:20	3.30	141.70	24.67
4/12/2006 16:20	3.32	145.87	24.66
4/12/2006 16:20	3.35	140.42	24.66
4/12/2006 16:20	3.42	139.06	24.67
4/12/2006 16:20	3.37	148.90	24.66
4/12/2006 16:20	3.35	151.31	24.66
4/12/2006 16:21	3.18	131.67	24.67
4/12/2006 16:21	3.14	135.79	24.66
4/12/2006 16:21	3.08	132.48	24.66
4/12/2006 16:21	2.98	132.64	24.67
4/12/2006 16:21	2.96	132.30	24.66
4/12/2006 16:21	2.97	147.45	24.66
4/12/2006 16:21	2.98	138.08	24.67
4/12/2006 16:21	2.99	141.26	24.66
4/12/2006 16:21	2.99	136.17	24.66
4/12/2006 16:21	3.06	156.18	24.67
4/12/2006 16:21	3.06	144.71	24.66
4/12/2006 16:21	3.08	149.76	24.66
4/12/2006 16:21	3.08	140.11	24.67
4/12/2006 16:21	3.08	136.72	24.66
4/12/2006 16:21	3.06	153.15	24.66
4/12/2006 16:21	2.93	137.59	24.67
4/12/2006 16:21	2.92	139.05	24.66
4/12/2006 16:21	2.90	144.02	24.66
4/12/2006 16:22	2.68	144.99	24.67
4/12/2006 16:22	2.67	145.41	24.66
4/12/2006 16:22	2.68	145.54	24.66
4/12/2006 16:22	2.51	162.77	24.67
4/12/2006 16:22	2.51	163.12	24.66
4/12/2006 16:22	2.52	163.00	24.66
4/12/2006 16:22	2.47	159.07	24.66
4/12/2006 16:22	2.49	150.76	24.66
4/12/2006 16:22	2.51	159.42	24.66
4/12/2006 16:22	2.55	150.99	24.66
4/12/2006 16:22	2.57	141.14	24.66
4/12/2006 16:22	2.59	156.68	24.66
4/12/2006 16:22	2.55	155.72	24.67
4/12/2006 16:22	2.56	157.84	24.66
4/12/2006 16:22	2.56	144.90	24.66
4/12/2006 16:22	2.41	146.56	24.66
4/12/2006 16:22	2.40	149.75	24.66
4/12/2006 16:22	2.39	144.54	24.66

4/12/2006 16:23	2.16	154.17	24.67
4/12/2006 16:23	2.15	156.20	24.66
4/12/2006 16:23	2.14	150.86	24.66
4/12/2006 16:23	1.91	142.21	24.67
4/12/2006 16:23	1.91	151.38	24.66
4/12/2006 16:23	1.89	147.89	24.66
4/12/2006 16:23	1.66	142.27	24.67
4/12/2006 16:23	1.64	137.48	24.66
4/12/2006 16:23	1.64	150.33	24.66
4/12/2006 16:23	1.54	148.67	24.66
4/12/2006 16:23	1.55	151.62	24.66
4/12/2006 16:23	1.58	147.74	24.66
4/12/2006 16:23	1.63	150.74	24.66
4/12/2006 16:23	1.66	158.72	24.66
4/12/2006 16:23	1.68	159.13	24.66
4/12/2006 16:23	1.72	157.45	24.66
4/12/2006 16:23	1.74	152.84	24.66
4/12/2006 16:23	1.77	161.27	24.66
4/12/2006 16:24	1.77	157.18	24.66
4/12/2006 16:24	1.78	159.87	24.66
4/12/2006 16:24	1.79	148.79	24.66
4/12/2006 16:24	1.65	151.08	24.66
4/12/2006 16:24	1.64	158.90	24.66
4/12/2006 16:24	1.64	151.28	24.66
4/12/2006 16:24	1.45	151.43	24.66
4/12/2006 16:24	1.44	150.76	24.66
4/12/2006 16:24	1.44	149.93	24.66
4/12/2006 16:24	1.32	154.02	24.67
4/12/2006 16:24	1.33	161.48	24.67
4/12/2006 16:24	1.35	157.71	24.67
4/12/2006 16:24	1.30	156.33	24.67
4/12/2006 16:24	1.31	156.98	24.67
4/12/2006 16:24	1.31	135.43	24.68
4/12/2006 16:24	1.23	148.54	24.68
4/12/2006 16:24	1.23	149.52	24.68
4/12/2006 16:24	1.23	135.38	24.68
4/12/2006 16:25	1.10	134.79	24.67
4/12/2006 16:25	1.02	131.97	24.67
4/12/2006 16:25	1.02	137.44	24.67
4/12/2006 16:25	1.02	127.72	24.67
4/12/2006 16:25	1.02	19.65	24.66
4/12/2006 16:25	1.01	4.84	24.66
4/12/2006 16:25	1.01	0.24	24.57
4/12/2006 16:25	1.01	0.24	24.56
4/12/2006 16:25	1.01	0.24	24.56
4/12/2006 16:25	1.01	0.24	24.52
4/12/2006 16:25	1.01	0.25	24.51
4/12/2006 16:25	1.01	0.24	24.50
4/12/2006 16:25	1.01	0.24	24.47
4/12/2006 16:25	1.01	0.24	24.46
4/12/2006 16:25	1.01	0.24	24.46
4/12/2006 16:25	1.01	0.24	24.47
4/12/2006 16:25	1.01	0.24	24.46
4/12/2006 16:25	1.01	0.24	24.46
4/12/2006 16:26	1.01	0.24	24.46
4/12/2006 16:26	1.01	0.24	24.45
4/12/2006 16:26	1.01	0.25	24.46
4/12/2006 16:26	1.01	0.24	24.48
4/12/2006 16:26	1.03	0.24	24.55
4/12/2006 16:26	1.04	2.33	24.61
4/12/2006 16:26	1.48	129.68	24.66
4/12/2006 16:26	1.55	124.89	24.65
4/12/2006 16:26	1.61	130.62	24.65
4/12/2006 16:26	2.03	127.44	24.66
4/12/2006 16:26	2.07	124.85	24.66

4/12/2006 16:26	2.09	126.11	24.66
4/12/2006 16:26	2.11	126.38	24.66
4/12/2006 16:26	2.10	125.46	24.66
4/12/2006 16:26	2.11	132.28	24.66
4/12/2006 16:26	1.83	125.68	24.66
4/12/2006 16:26	1.78	125.50	24.66
4/12/2006 16:26	1.72	125.02	24.66
4/12/2006 16:27	1.30	124.23	24.66
4/12/2006 16:27	1.25	123.86	24.65
4/12/2006 16:27	1.23	127.85	24.65
4/12/2006 16:27	1.01	0.25	24.62
4/12/2006 16:27	1.01	0.23	24.59
4/12/2006 16:27	1.01	0.24	24.58
4/12/2006 16:27	1.01	0.24	24.58
4/12/2006 16:27	1.01	0.24	24.57
4/12/2006 16:27	1.01	0.24	24.57
4/12/2006 16:27	1.01	0.24	24.58
4/12/2006 16:27	1.01	0.25	24.57
4/12/2006 16:27	1.01	0.25	24.57
4/12/2006 16:27	1.01	0.25	24.56
4/12/2006 16:27	1.01	0.24	24.56
4/12/2006 16:27	1.01	0.24	24.56
4/12/2006 16:27	1.01	0.24	24.57
4/12/2006 16:27	1.01	0.24	24.56
4/12/2006 16:27	1.01	0.24	24.56
4/12/2006 16:28	1.13	130.65	24.66
4/12/2006 16:28	1.13	140.75	24.66
4/12/2006 16:28	1.13	141.97	24.66
4/12/2006 16:28	1.13	142.16	24.67
4/12/2006 16:28	1.15	127.26	24.66
4/12/2006 16:28	1.14	129.46	24.66
4/12/2006 16:28	1.01	4.81	24.65
4/12/2006 16:28	1.01	4.80	24.62
4/12/2006 16:28	1.01	4.79	24.61
4/12/2006 16:28	1.01	0.24	24.56
4/12/2006 16:28	1.01	0.24	24.55
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4/12/2006 16:28	1.01	0.24	24.55
4/12/2006 16:28	1.01	0.24	24.54
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4/12/2006 16:29	1.01	0.25	24.57
4/12/2006 16:29	1.01	0.24	24.56
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4/12/2006 16:29	1.01	0.24	24.55
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4/12/2006 16:29	1.01	0.24	24.53
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4/12/2006 16:29	1.01	0.24	24.48
4/12/2006 16:29	1.01	0.24	24.47
4/12/2006 16:29	1.01	0.24	24.48
4/12/2006 16:29	1.01	0.24	24.47
4/12/2006 16:29	1.01	0.24	24.46
4/12/2006 16:29	1.01	0.24	24.44
4/12/2006 16:29	1.01	0.24	24.42
4/12/2006 16:29	1.01	0.24	24.41
4/12/2006 16:29	1.01	0.24	24.41
4/12/2006 16:29	1.01	0.25	24.39
4/12/2006 16:29	1.01	0.24	24.40
4/12/2006 16:30	1.01	0.23	24.42
4/12/2006 16:30	1.01	0.24	24.40
4/12/2006 16:30	1.01	0.24	24.39
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4/12/2006 16:30	1.01	0.24	24.40
4/12/2006 16:30	1.01	0.24	24.39
4/12/2006 16:30	1.01	0.25	24.40
4/12/2006 16:30	1.01	0.24	24.42
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4/12/2006 16:30	1.01	0.23	24.41
4/12/2006 16:30	1.01	0.24	24.44
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4/12/2006 16:30	1.01	0.23	24.48
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4/12/2006 16:31	1.01	0.24	24.47
4/12/2006 16:31	1.01	0.24	24.47
4/12/2006 16:31	1.01	0.24	24.47
4/12/2006 16:31	1.01	0.24	24.46
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4/12/2006 16:31	1.01	0.24	24.46
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4/12/2006 16:32	1.01	0.24	24.41
4/12/2006 16:32	1.01	0.24	24.41
4/12/2006 16:32	1.01	0.24	24.42
4/12/2006 16:32	1.01	0.24	24.58
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4/12/2006 16:32	1.01	0.24	24.62
4/12/2006 16:32	1.01	0.24	24.61
4/12/2006 16:32	1.01	0.25	24.62
4/12/2006 16:32	1.01	0.23	24.67
4/12/2006 16:32	1.01	0.24	24.66
4/12/2006 16:32	1.01	0.24	24.64
4/12/2006 16:32	1.01	0.33	24.56
4/12/2006 16:32	1.01	0.76	24.55
4/12/2006 16:32	1.01	0.26	24.55
4/12/2006 16:32	1.01	0.92	24.56
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4/12/2006 16:33	1.01	0.13	24.56
4/12/2006 16:33	1.01	650.02	24.53
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4/12/2006 16:34	1.01	787.85	24.52
4/12/2006 16:34	1.01	800.17	24.51
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4/12/2006 16:34	1.01	820.12	24.44
4/12/2006 16:34	1.01	820.47	24.43
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4/12/2006 16:35	1.01	866.51	24.41
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4/12/2006 16:35	1.01	874.44	24.36
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4/12/2006 16:35	1.01	832.14	24.43
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4/12/2006 16:36	1.01	942.73	24.36
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4/12/2006 16:37	1.01	898.40	24.57
4/12/2006 16:37	1.01	915.15	24.57
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4/12/2006 16:37	1.01	957.07	24.64
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4/12/2006 16:37	1.01	955.66	24.68
4/12/2006 16:37	1.01	954.59	24.68
4/12/2006 16:37	1.01	959.89	24.68
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4/12/2006 16:38	1.01	948.79	24.71
4/12/2006 16:38	1.01	940.44	24.74
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4/12/2006 16:38	1.01	940.09	24.77
4/12/2006 16:38	1.01	940.44	24.80
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4/12/2006 16:38	1.01	939.14	24.79
4/12/2006 16:38	1.01	939.87	24.80
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4/12/2006 16:39	1.01	937.50	24.81
4/12/2006 16:39	1.01	937.61	24.81
4/12/2006 16:39	1.01	938.07	24.81
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4/12/2006 16:39	1.01	969.77	24.88
4/12/2006 16:39	1.01	969.85	24.88
4/12/2006 16:39	1.01	969.89	24.89
4/12/2006 16:39	1.01	969.51	24.88
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4/12/2006 16:40	1.01	932.04	24.85
4/12/2006 16:40	1.01	931.47	24.86
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4/12/2006 16:41	1.01	933.19	24.96
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4/12/2006 16:41	1.01	934.03	24.97
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4/12/2006 16:41	1.01	935.75	25.00
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4/12/2006 16:42	1.01	935.06	25.01
4/12/2006 16:42	1.01	935.13	25.00
4/12/2006 16:42	1.01	934.94	25.00
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4/12/2006 16:44	1.01	936.13	25.14
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4/12/2006 16:50	1.01	511.86	25.66
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4/12/2006 16:50	1.01	512.89	25.67
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4/12/2006 17:04	1.01	582.81	25.95
4/12/2006 17:04	1.01	582.96	25.95
4/12/2006 17:04	1.01	583.08	25.95
4/12/2006 17:05	1.01	583.80	25.97
4/12/2006 17:05	1.01	583.80	25.97
4/12/2006 17:05	1.01	583.80	25.97
4/12/2006 17:05	1.01	584.37	25.99
4/12/2006 17:05	1.01	584.60	25.98
4/12/2006 17:05	1.01	584.60	25.98
4/12/2006 17:05	1.01	585.25	26.00
4/12/2006 17:05	1.01	585.29	25.99
4/12/2006 17:05	1.01	585.52	25.99
4/12/2006 17:05	1.01	585.59	26.01
4/12/2006 17:05	1.01	585.67	26.00
4/12/2006 17:05	1.01	585.63	26.00
4/12/2006 17:05	1.01	586.85	26.02
4/12/2006 17:05	1.01	587.01	26.01
4/12/2006 17:05	1.01	587.08	26.01
4/12/2006 17:05	1.01	586.78	26.02
4/12/2006 17:05	1.01	586.81	26.02
4/12/2006 17:05	1.01	587.08	26.02
4/12/2006 17:06	1.01	588.38	26.03
4/12/2006 17:06	1.01	588.42	26.02
4/12/2006 17:06	1.01	588.65	26.02
4/12/2006 17:06	1.01	589.56	26.02
4/12/2006 17:06	1.01	589.83	26.02
4/12/2006 17:06	1.01	589.90	26.02

4/12/2006 17:06	1.01	589.41	26.03
4/12/2006 17:06	1.01	589.56	26.03
4/12/2006 17:06	1.01	589.68	26.02
4/12/2006 17:06	1.01	590.82	26.04
4/12/2006 17:06	1.01	590.78	26.03
4/12/2006 17:06	1.01	590.86	26.03
4/12/2006 17:06	1.01	592.08	26.05
4/12/2006 17:06	1.01	592.04	26.04
4/12/2006 17:06	1.01	592.46	26.05
4/12/2006 17:06	1.01	593.26	26.06
4/12/2006 17:06	1.01	593.34	26.05
4/12/2006 17:06	1.01	593.41	26.05
4/12/2006 17:07	1.01	594.56	26.06
4/12/2006 17:07	1.01	594.63	26.05
4/12/2006 17:07	1.01	594.86	26.06
4/12/2006 17:07	1.01	593.99	26.07
4/12/2006 17:07	1.01	593.99	26.06
4/12/2006 17:07	1.01	594.25	26.05
4/12/2006 17:07	1.01	595.21	26.07
4/12/2006 17:07	1.01	595.44	26.06
4/12/2006 17:07	1.01	595.66	26.06
4/12/2006 17:07	1.01	596.54	26.06
4/12/2006 17:07	1.01	596.62	26.06
4/12/2006 17:07	1.01	596.77	26.06
4/12/2006 17:07	1.01	597.61	26.07
4/12/2006 17:07	1.01	597.69	26.07
4/12/2006 17:07	1.01	597.84	26.07
4/12/2006 17:07	1.01	598.83	26.08
4/12/2006 17:07	1.01	598.98	26.08
4/12/2006 17:07	1.01	599.06	26.07
4/12/2006 17:08	1.01	600.13	26.08
4/12/2006 17:08	1.01	600.13	26.08
4/12/2006 17:08	1.01	600.32	26.07
4/12/2006 17:08	1.01	601.39	26.09
4/12/2006 17:08	1.01	601.39	26.08
4/12/2006 17:08	1.01	601.54	26.08
4/12/2006 17:08	1.01	602.30	26.10